PB87-145702

Gray Iron Foundry Industry
Particulate Emissions
Source Category Report

GCA Corp., Bedford, MA

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Dec 86

U.S. Department of Commerce
National Technical Information Service
NTIS

PB87-145702

EPA/600/7-86/054
December 1986

GRAY IRON FOUNDRY INDUSTRY PARTICULATE EMISSIONS: SOURCE CATEGORY REPORT

by

John Jeffery, John Fitzgerald,
and Paul Wolf

GCA Corporation
GCA/Technology Division, Inc.
Bedford, Massachusetts 01730

Contract 68-02-3157
Technical Directive No. 17

EPA Project Officer: Dale L. Harmon
Air and Energy Engineering Research Laboratory
Research Triangle Park, North Carolina 27711

AIR AND ENERGY ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/7-86/054		PB87 145702/AS

4. TITLE AND SUBTITLE	5. REPORT DATE
Gray Iron Foundry Industry Particulate Emissions: Source Category Report	December 1986
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
John Jeffery, John Fitzgerald, and Paul Wolf	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
GCA/Technology Division, Inc. 213 Burlington Road Bedford, Massachusetts 01730	11. CONTRACT/GRANT NO. 68-02-3157, Task 17
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
EPA, Office of Research and Development **Air and Energy Engineering Research Laboratory** **Research Triangle Park, NC 27711**	Task Final; 6/83 - 8/86 14. SPONSORING AGENCY CODE **EPA/600/13**

15. SUPPLEMENTARY NOTES AEERL project officer is Dale L. Harmon, Mail Drop 61, 919/541-2429.

16. ABSTRACT The report gives results of a study to develop particulate emission factors based on cutoff size for inhalable particles for the gray iron foundry industry. After a review of available information characterizing particulate emissions from gray iron foundries, the data were summarized and rated in terms of reliability. Size specific emission factors were developed from these data for the major processes used in the manufacture of gray iron. A detailed process description is presented with emphasis on factors affecting the generation of emissions. A replacement for Section 7.10 (Gray Iron Foundries) of EPA report AP-42, A Compilation of Air Pollutant Emissions Factors, was prepared, containing the size specific emission factors developed during the program.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Gray Iron	Stationary Sources	11F
Foundries	Particulate	13I
Particles	Inhalable Particles	14G
Emission	Emission Factors	
Industrial Processes		

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to Public	**Unclassified**	85
	20. SECURITY CLASS *(This page)* **Unclassified**	22. PRICE

EPA Form 2220-1 (9-73)

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

The objective of this study was to develop particulate emission factors based on cutoff size for inhalable particles for the gray iron foundry industry. After a review of available information characterizing particulate emissions from gray iron foundries, the data were summarized and rated in terms of reliability. Size specific emission factors were developed from these data for the major processes used in the manufacture of gray iron. A detailed process description was presented with emphasis on factors affecting the generation of emissions. A replacement for Section 7.10 (Gray Iron Foundries) of EPA report AP-42, A Compilation of Air Pollutant Emissions Factors, was prepared, containing the size specific emission factors developed during this program.

CONTENTS

Abstract iii
Figures vi
Tables vii

1. Introduction 1
2. Industry Description 4
   Gray Iron Foundry Process Operations 5
   Gray Iron Foundry Emissions and Controls 11
3. Gray Iron Foundry Emission Factors 16
   Data Review Procedures 16
   Ranking of Test Data for Gray Iron Foundry Processes 27
   Emission Factor Calculation 36
   Total Particulate Emission Factor Calculation 36
   Particle Sizing Emission Factor Calculation 50
4. Proposed AP-42 Section 51
   References for Sections 1 to 3 73

Preceding page blank

FIGURES

Number		Page
1	Iron foundry process flow and emission sources	6
2	Uncontrolled cupola particle size distribution	21
3	Controlled (baghouse) cupola particle size distribution. .	22
4	Controlled (venturi scrubber) cupola particle size distribution.	23
5	Uncontrolled pouring and cooling emissions--particle size distribution	24
6	Uncontrolled shakeout emissions--particle size distribution.	25
7	Uncontrolled electric arc furnace particle size distribution.	26
7.10-1	Typical iron foundry diagram	53
7.10-2	Emission points in a typical iron foundry.	54
7.10-3	Particle size distribution for uncontrolled cupola	64
7.10-4	Particle size distribution for baghouse controlled cupola.	65
7.10-5	Particle size distribution for venturi scrubber controlled cupola	66
7.10-6	Particle size distribution for uncontrolled electric arc furnace	67
7.10-7	Particle size distribution for uncontrolled pouring and cooling	68
7.10-8	Particle size distribution for uncontrolled shakeout . . .	69

TABLES

Number		Page
1	Gray Iron Core Types	12
2a	Emission Factors for Gray Iron Furnaces	17
2b	Particulate Emission Factors for Ancillary Process Operations and Fugitive Sources at Gray Iron Foundries	18
3	Specific Particle Size Distribution Data and Emission Factors for Gray Iron Foundries	19
4	Particulate Emission Factor: Cupola--Uncontrolled	37
5	Particulate Emission Factor: Cupola--With Baghouse	38
6	Particulate Emission Factor: Cupola--With ESP	38
7	Particulate Emission Factor: Cupola--With Scrubber (All Types Except Venturi)	39
8	Particulate Emission Factor: Cupola--With Venturi Scrubber	40
9	Particulate Emission Factor: Electric Arc Furnace--Uncontrolled	41
10	Particulate Emission Factor: Electric Arc Furnace--With Baghouse	42
11	Particulate Emission Factor: Induction Furnace--Uncontrolled	43
12	Particulate Emission Factor: Induction Furnace--With Baghouse	43
13	Particulate Emission Factor: Reverberatory Furnace--Uncontrolled	44
14	Particulate Emission Factor: Reverberatory Furnace--With Baghouse	44

TABLES (continued)

Number		Page
15	Particulate Emission Factor: Pouring and Cooling--Uncontrolled	45
16	Particulate Emission Factor: Magnesium Inoculation--Uncontrolled	45
17	Particulate Emission Factor: Shakeout Uncontrolled	46
18	Particulate Emission Factor: Sand Handling System--Uncontrolled	46
19	Particulate Emission Factor: Sand Handling--With Scrubber	47
20	Particulate Emission Factor: Sand Handling System--With Venturi Scrubber	47
21	Particulate Emission Factor: Sand Handling System--With Baghouse	47
7.10-1	Chemical Composition of Ferrous Castings by Percentage	55
7.10-2	Emission Factors for Gray Iron Furnaces	59
7.10-3	Gaseous and Lead Emission Factors for Gray Iron Furnaces Emission Factor Rating: B	60
7.10-4	Particulate Emission Factors for Ancillary Process Operations and Fugitive Sources at Gray Iron Foundries	61
7.10-5	Particle Size Distribution Data and Emission Factors for Gray Iron Foundries	62

SECTION 1

INTRODUCTION

During the mid to late 1970s, the U.S. Environmental Protection Agency was engaged in multiple research programs to study the major emission sources associated with the ferrous metallurgical industries. These studies were directed toward process emissions and effluents which are multimedia in nature.

In support of the overall emission assessment program, the Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina (IERL-RTP) initiated a program to study particulate emissions released from steel and metallurgical processes. The program dealt with fugitive as well as source-generated total and inhalable particulate matter.

GCA/Technology Division was issued a task to support the inhalable particulate program administered by IERL-RTP. The purpose of this program was to provide a summary of the best available information on particulate matter emissions prevalent in the gray iron foundry industry. Of primary concern was the development of reliable total and size specific emission factors. This included total particulate emission rates and particle sizing data for both uncontrolled emission sources and those controlled by gas cleaning devices.

A second objective of this program was to prepare an update of AP-42, Section 7.10 for Gray Iron Foundries, "A Compilation of Emission Factors" which was last revised in April 1981. An additional objective was to investigate and present a current description of the gray iron foundry industry.

Based on an extensive literature search, total particulate and particle size emissions data were reviewed, analyzed, summarized and ranked according to the criteria provided in the report "Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections," April 1980. The available data were rated as follows:

- A - Tests performed by a sound methodology and reported in enough detail for adequate validation. These tests were not necessarily EPA reference method tests, although such reference methods were certainly to be used as a guide.

- B - Tests that were performed by a generally sound methodology, but lacked enough detail for adequate validation.

- C - Tests that were based on an untested or new methodology or that lacked a significant amount of background data.

- D - Tests that were based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

Following the completion of the data ranking segment, emission factors were calculated using the highest quality data available. Calculated emission factors were subsequently assigned a quality rating based on the type of data used to derive the emission factor.

Quality emission factor ratings are defined below.

- A - Excellent--Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. This source category* is specific enough to minimize variability within the source category population.

- B - Above average--Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. As in the A rating, the source category is specific enough to minimize variability within the source category population.

- C - Average--Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.

- D - Below average--The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are footnoted in the emission factor table.

- E - Poor--The emission factor was developed from C- and D-rated test data, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are always footnoted.

---

*Source category: A category in the emission factor table for which an emission factor has been calculated; generally a single process.

Process and control system descriptions and general industry profile information were obtained, evaluated, summarized and presented as general background information. It was not the objective of this program to provide detailed engineering analyses, product specifications, or detailed evaluations of trends in the industry.

This report was structured according to the "Outline for Source Category Reports" which was included in the technical directive to conduct this program. There is necessary duplication of information between Section 4, the AP-42 section, and Sections 1 through 3 of the report in order that the AP-42 section can stand alone. This revision of Section 7.10 of AP-42 is based on additional particulate matter data obtained during the recent test program supported by Office of Research and Development (ORD).

No environmental measurements were conducted during this program. Therefore, no separate QA section is contained in this report. The quality of the existing data has been evaluated based on the criteria described above.

SECTION 2

INDUSTRY DESCRIPTION

A grey iron foundry is a facility in which scrap metal and pig iron are melted and poured, and cast into molds to form iron castings. The common product formed is a gray iron casting which has a carbon content between 2 and 4 percent by weight. Ductille and malleable iron* can be formed from gray iron either by inoculation of the iron in the molten state of by heat treating.

The iron foundry industry in the U.S. has undergone major changes during the last 35 years. Today the trend shows a continued decrease in the number of foundries, from 3,200 in 1947 to approximately 1,400 today. [1,2] The iron foundry production rates have been maintained or increased during that time, up until the recent recession of 1980/1981. These trends reflect a reduction in the number of small foundries, and an increase in the size and production rate of larger foundries. The American Foundryman's Society reports that over 25% of the casting capacity in the U.S. has been closed.

Iron foundries consist of five basic operations which include raw materials storage and handling, metal melting, core making, pouring of the molten metal into a mold, and removal of solid castings from the mold. Other operations which occur in many foundries are preparation and assembly of sand molds and cores, mold cooling, shakeout, cleaning and finishing, sand handling and preparation, and hot metal inoculation. The basic raw materials which enter (2) metallic materials including iron and steel scrap, borings and turnings, limited quantities of pig iron, and foundry returns; and (3) fluxing agents and limited quantities of inoculants and alloying agents.

---

*Ductile iron is normally a gray cast iron that has been suitably treated with a nodularizing agent (e.g., magnesium) so that all or the major portion of its graphitic carbon has a nodular or spherulitic form as cast.[1]

Malleable iron is a mixture of iron and carbon, including smaller amounts of silicon, manganese, sulfur and phosphorous, which, after being cast as white iron, is converted structurally by heat treatment into a matrix of ferrite-containing nodules of temper carbon, and substantially free of all combined carbon.[2]

The generation of pollutants at a foundry occurs at almost every step of the iron foundry process. Emmision sources are categorized as process, fugitive of open fugitive and both gaseous and particulate emissions are produced as shown in Figure 1. The primary gaseous pollutants emitted included carbon monoxide and volatile organic compounds (VOC), such as formaldehyde, amies, phenols and hydrocarbons. Particulate emissions consist mainly of fine metallic fumes, silica dust, and metallic oxides. Reported emission rates can bary from foundry to foundry by several orders of magnitude and within the same foundry by up to one order of magnitude depending on processes used and the castings being produced.

GRAY IRON FOUNDRY PROCESS OPERATIONS

Furnace Charge Preparation

The major groups of raw materials required for furnace charging are metallics, fluxes and fuels. Metallic raw materials include pig iron, iron and steel scrap, foundry returns and metal turnings. Fluxes include carbonates (limestone, dolomite), fluoride (fluorspar), and carbide compounds (calcium carbide).[3,5] Fuels include coal, oil, natural gas, and coke. Electricity is also used as a power source. Coal, oil, and natural gas are used to fire reverberatory furnaces. Coke, a derivative of coal, is used as a fuel in cupola furnaces. These raw materials must be obtained, transported to the facility and further handled and distributed within the facility according to the process scheme.

The scrap metal sometimes requires preparation for charging to the furnace. Depending on the condition of the scrap and the type of furnace used for the melting process, the scrap may have to be cut, degreased and dried. Other raw materials, such as the coke and fluxes, require little preparation other than weighing the quantities required for a charge. The actual charge make-up and degree of preparation are dependent on the type of furnace used to melt the metal, scrap composition, and product specification.

Metal Melting

Basically there are four types of furnaces used in the gray iron industry: (1) cupola, (2) electric arc, (3) electric induction, and (4) reverberatory.

Cupola Furnace--

The cupola has been and currently is the primary furnace type used to melt foundry iron produced in the U.S.[3] Forecasts in the early 1970s predicted a steady decline in cupola use, with replacement by electric arc and induction furnaces. However, the high cost of electricity in the 1970s and 1980s has caused a resurgence in the use of the cupola.

The cupola is basically a cylindrical vertical furnace constructed of steel and usually lined with refractory brick. There are also unlined cupolas which are water cooled.

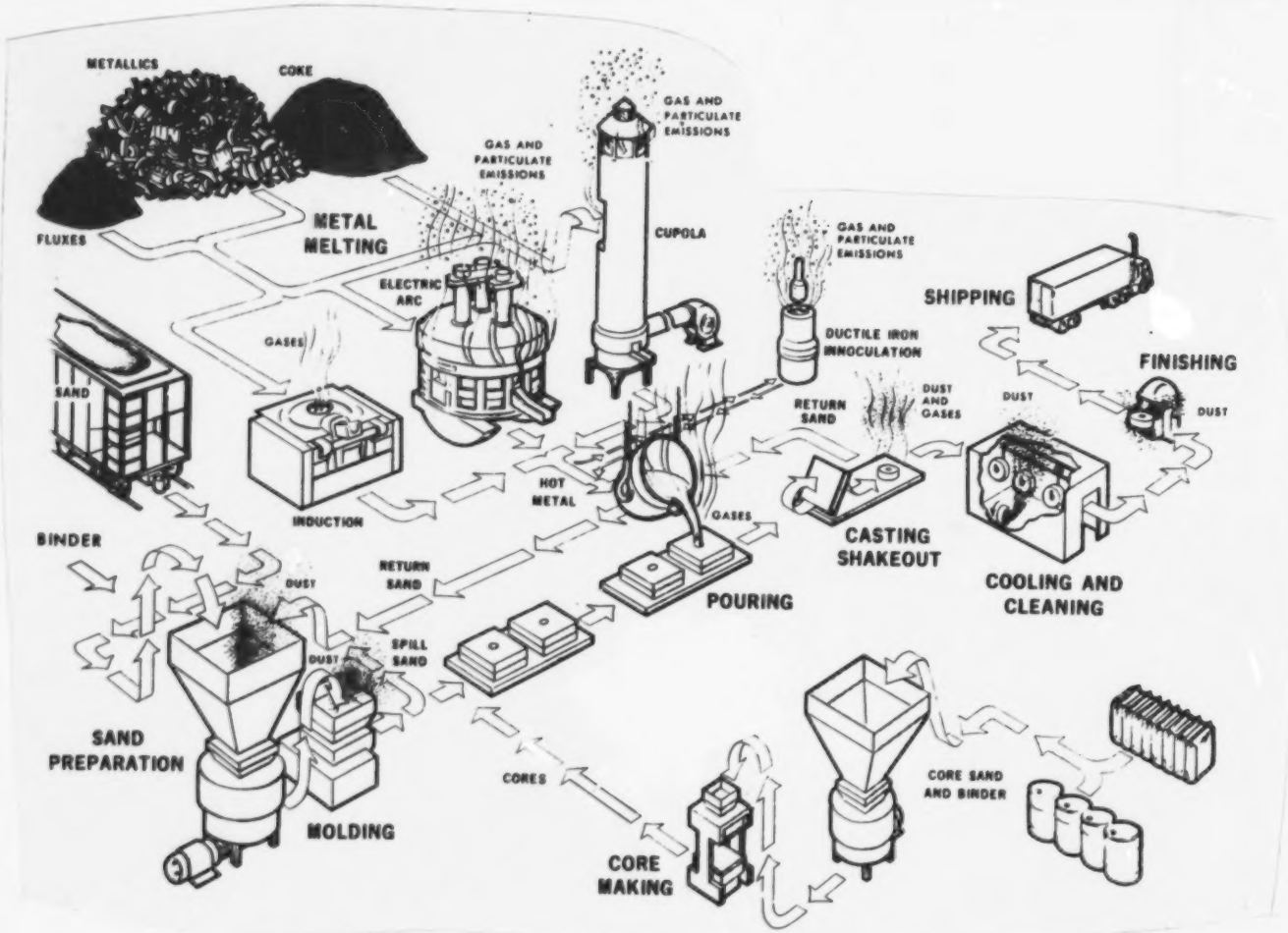

Figure 1. Iron foundry process flow and emission sources.[2]

The bottom of the cupola, which can be opened, is packed with sand. A layer of coke is placed on top of the sand at the start of a melt cycle and subsequently ignited. The cupola is then charged with alternate layers of metal, coke and fluxes. A typical charge, presented as percent of iron input, is:[4]

- Scrap steel - 42 percent;
- Foundry returns - 58 percent;
- Total coke - 14 percent; and
- Fluxes - 3 percent;

Combustion of the coke is aided by combustion air introduced through tuyeres. Tuyeres are nozzles which protrude through the frunace shell and project a few feet above the sand bed. The iron is melted by the burning coke, and the molten metal flows down the cupola. As the melt proceeds, new charges are added at the top. The flux removes non-metallic impurities in the iron to form slag. The molten iron and slag are periodically removed through tapholes also located above the sand bed. Periodically, on a daily, weekly or monthy basis the cupola bottom is opened and the unburned materials removed.

Cupolas vary greatly in size, ranging from an inside diameter of 46 cm (18 in.) to greater than 254 cm (100 in.).[5] The melting capacities of cupolas can range from 0.5 to >52 Mg/hr (1 to >100 tons/hr).

Electric Arc Furnace--

The electric are furnace (EAF) is the second most common furnace used for melting iron.[3] The direct-arc electric furnace is a cylindrical vessel constructed of a steel shell lined with refractory brick. Its refractory-lined roof has three graphite electrodes inserted through it. Charging the furnace is accomplished in one of three ways, depending on the structural design of the EAF. Most EAFs have removable roofs to allow direct charging to the furnace via a dump bucket handled by an overhead crane. Furnaces with a fixed-roof use a chute passing through an opening in the roof. In a few cases, charging may be conducted through doors located on the side of the furnace. A typical charge consists of 50 to 60 percent scrap iron, 37 to 45 percent scrap steel, 0.5 to 1.1 percent silicon and 1.3 to 1.7 percent carbon-raisers.[6] Carbon raisers are additives introduced into the molten bath to raise the carbon level, if required. The actual charge composition at individual iron foundries can vary substantially, depending on scrap availability, and grade of iron produced.

The scrap charge is melted by heat from electrical arcing between the electrodes which are inserted directly into the charge through openings in the furnace roof. Power for these electrodes is supplied using three-phase alternating current.

The EAF has some distinct advantages over the cupola. It allows for better control of the melt chemistry, and is also easier to operate. The furnace yield is more efficient than a cupola, with 94 to 98 percent of the EAF charge recovered as iron.[6] Iron foundry EAFs typically have holding capacities of 0.13 to 34 Mg (0.25 to 65 tons)[4] and melt rates of up to 10 Mg/hr (20 tons/hr).[5]

Electric Induction Furnace--

Induction furnaces are the third most common furnace used for melting iron.[3] There are two types of induction furnaces currently in use today: coreless and channel. The coreless induction furnace is a cylindrical or cup-shaped vessel lined with a refractory material and fitted with water-cooled electrical conductors around its circumference. The wire coils are energized with an alternating current; the resulting magnetic field raises the metal temperature in the furnace to that required for melting and refining. When the metal has become molten, the magnetic fields generated by the coil interact with magnetic fields generated within the metal. This results in the metal undergoing a strong stirring action. This type of furnace is referred to as a coreless induction furnace because the electrical coil is wrapped around the furnace exterior.

The channel induction furnace differs from the coreless furnace in that the heating coil passes horizontally through the furnace. The channel furnace requires a continuous circuit of iron or metal around this core within the furnace, and only the iron in the lower portion of the furnace immediately surrounding the channel is heated. Some residual metal must always be present in the furnace for it to operate.

Induction furnaces are best suited for batch type operations although some have been recently designed for continuous operation. The coreless type is better suited for melting whereas the channel type is better suited for holding or superheating metal.

The induction furnaces are very energy efficient, as exhibited by the very low melting losses and the high recovery of alloy. These furnaces are usually charged with scrap steel and cast iron scrap, foundry returns, ferrosilicon and carbon in amounts consistent with the chemical requirements of the product. The charge is often dried to prevent explosions during charging when there is a heel of molten metal present.

After the metal has become molten, pelletized coke is added to adjust the carbon content. Because it is not a refining furnace, great care must be taken to control the composition of the scrap metal charge to prevent metal contamination.[4] Induction furnaces are often used in conjunction with cupola furnaces where the cupola furnace melts the charge and the molten iron is subsequently super-heated in the induction furnace.

Reverberatory Furnace--

Use of the reverberatory furnace for melting iron is essentially obsolete in the U.S. They are still used in some foreign countries.

furnaces serve two primary purposes in the foundry industry; (1) as a melting unit, and (2) as a molten metal treatment unit, commonly known as a duplexing furnace. In the latter case, the reverberatory furnace is used in conjunction with a cupola to produce malleable iron. These furnaces can accumulate charge capacities up to 21 Mg (40 tons).

When used as a melting unit, reverberatory furnaces are smaller (up to 1 Mg (2 tons) capacity), and are horizontally fired with coal, natural gas, or oil from one end and waste gases removed from the opposite end. These furnaces generally emit lower levels of particulate matter.

Molten Metal Treatments

After the iron is melted it can either be poured into a mold directly or it can be further treated. Treatment processes include either duplexing, to form malleable iron, or inoculation, to form ductile iron. Duplexing usually involves a cupola furnace used in conjunction with an electric induction or reverberatory furnace to superheat the molten iron.

Inoculation is the process of adding a light metal such as magnesium to the molten iron to form ductile iron. Magnesium is usually added in an alloy form which contains silicon, nickel, or copper. The melting point of the iron is higher than the vaporization point of the magnesium, which upon addition of this metal produces a violent reaction.

Pouring and Cooling

Metal which has been melted and treated, is poured into a mold. The method of pouring is dependent on various factors, such as the mold type, size of casting and the degree of mechanization within the foundry. Molten metal is either brought to the molds in a ladle and poured manually, or if the foundry is mechanized, the molds are brought through a pouring station on a conveyor system and the molten iron is poured manually or automatically into the molds. If the molds are very large, the metal must be brought to the molds. After the completion of pouring, the metal and molds are left to cool until the castings are ready for removal. Cooling time may vary from a few minutes to several hours on the automatic conveyors or overnight at small non-mechanized foundries.[4]

Shakeout

Castings are separated from the mold when the cooling process has been completed. The separation process is designated "shakeout" when sand molds are used. Shakeout involves placing the mold and casting on a vibrating grate which shakes and tumbles the casting, breaking up the sand molding. The sand falls through the grate and is collected, cleaned, and reused to make more molds. The castings may be cooled further if necessary and directed to a cleaning and finishing shop.

Cleaning and Finishing

The final process step involves casting cleaning and finishing. During this stage, sprues, gates, risers, fins and surface imperfections are knocked off or removed by grinding, cutting, or breaking. Sand or scale remaining on the cast is shot blasted using a blast cleaning unit. Finally, the iron casting may be heat treated to alter its coustituents in order that it may be put to different uses. This is done either in batch or continuous operations in a heat-treating furnace. Various heat treatments of iron castings are described as follows:[1]

1. For Gray and Ductile Iron

Stress relief	-	1000°-1250°F
Annealing	-	1250°-1650°F
Normalizing	-	1650°F
Quench and Temper	-	1550°-1600°F

2. For Malleable Iron

Annealing	-	1600°F

Sand Handling System

In many iron foundries the molds and cores used to shape the iron castings are made of sand. These molds, of which there are numerous types, are made primarily from sand that is cleaned, processed and reused many times. These recycling steps are performed by a sand handling system.

Recycled sand is analyzed and any additions required to meet the desired mold criteria are made. Next, the sand is conveyed to a sand muller where it is mixed with water additives and binding agents. Typical binding agents are derived from coal and clay. In large foundries there is usually a need to replace 10-20 percent of the sand with new sand.[4] The sand is then transferred to mold and core making stations.

Mold Making

There are many mold types for different casting methods. The green sand mold, however, is the oldest and still the most popular.

Green sand is composed of silica sand bonded with a moist clay that is plasticized with 4 to 6 percent water.[4] Fire clay, or the more customary bentonite clay is added in a concentration of approximately 4 to 6 percent by weight. Organic materials, primarily sea coal, pulverized cereals, wood flour, oat hulls, pitch or similar organic materials, are added in concentration of up to 8 percent.

A typical green sand mold is made in the following way. A pattern of the intended cast is made and is placed in the bottom of a flask which is called the drag. The prepared sand is then packed tightly around the pattern and the pattern removed. The top of the flask or cope is made in the same way and the two halves are joined forming the mold after setting the core(s).

Other types of molds include: inorganically bound molds which use plaster of paris or portland cement mixed with sand; organically bound sand molds which use sand bound with synthetic resin organic binders, graphite; and permanent molds made of ceramic, steel, or cast iron. The disadvantages of these other mold types are that the molds are more expensive and time consuming to manufacture.

Another process performed in conjunction with mold forming is the making of cores. A core is needed to make the internal cavities of a casting. Cores are made primarily of silica sand, organic or inorganic binders, and a liquid to activate the binding material.[1] These are then cured in an oven or a (core box) until the core is hard. The core is then placed inside the mold. Once the molten iron is poured and has hardened, the organic binders break down allowing the sand to flow out of the cavity. Similar to molds, there are many different types of cores. A description of the different core types and the formulation and curing methods is presented in Table 1.

Pattern Making

Most iron foundries have a pattern making shop where the shape of the cast is fabricated, usually out of wood or metal. The equipment used to make the patterns is similar to that found in a wood-working or metal-working shop.

GRAY IRON FOUNDRY EMISSIONS AND CONTROLS

Gray iron foundries produce both point source and fugitive emissions from many of their process operations. The greatest sources of emissions are the melting furnaces. The magnitude and type of emissions generated by the melting furnaces depend on many factors, specifically scrap cleanliness, type of auxiliary fuel, and the various chemical additions such as magnesium.

In addition to metal melting, pouring, cooling, and sand processing operations also generate emissions. Sand processing generates particulate matter from sand handling and shakeout. Pouring and cooling operations generate emissions comprised of molten metal fumes, vaporized organic matter and water contained within the sand matrix.

The following presentation describes the major gray iron foundry emission sources and typical emission control systems.

TABLE 1. GRAY IRON CORE TYPES

Type of Core	Typical Binder Addition, percent	Method of Curing	Curing Time
Oil Core	1.0 core oil 1.0 cereal 0 to 1 pitch or resin	Baked in an oven at 204 to 316°C (400 to 600°F)	1 to 2 hours
Shell core	3 to 5 phenolic and/or urea formaldehyde; hexamine activator	Cured as a thin layer on a heated metal pattern at 204 to 316°C (400 to 600°F)	1 to 3 minutes
Hot-box core	3 to 5 furan resin; phosphoric acid activator	Cured as a solid core in a heated metal pattern at 204 to 316°C (400 to 600°F)	1/2 to 1-1/2 minutes
Cold-set core	3 to 5 furan resin; phosphoric acid activator, or 1 to 2 core-oil; phosphoric acid activator	Hardens in the core box	1/2 to 3 hours
Cold-box Core	1 to 3 each of two resins; activator is a gas diluted with nitrogen	Hardens when the green core is gassed in the core box with polyisocyanate in air	10 to 30 seconds
CO_2 sand core[a]	2 to 4 sodium silicate; activator is CO_2 gas	Hardens when the green core is gassed in the box with carbon dioxide	20 to 60 seconds

[a]The "CO_2 process" is seldom used in iron foundries, because the cores do not break down well after being subjected to the casting temperatures employed.

Cupola Furnaces

Cupola furnaces are the predominant emission sources in the gray iron foundry industry. Cupola emissions include smoke, fumes, particulate matter and gases. The reason that these furnaces produce more emissions than any other process, including other melting furnaces, is that they are the only melting units that utilize limestone and coke, and are capable of handling dirty scrap.

Currently, a variety of technologies are utilized to control cupola emissions. The most common control devices are venturi scrubbers and baghouses. Venturi scrubbers are used most often with larger cupolas, whereas baghouses are used most often with medium to small-sized cupolas.[5] In general, baghouses tend to be more adaptable to the varying conditions of cupola exhaust than venturi scrubbers. Venturi scrubbers used at gray iron foundries include both fixed and variable throat designs. Venturi scrubbers are less effective for controlling fine particles (smaller than 2 microns) than coarser particles.

In addition to the two major types of control devices mentioned above, low energy scrubbers are used at some gray iron foundries. These have been categorized separately in the preparation of this AP-42 update. Wet caps, which are modified wet scrubbers, have also been categorized as low energy scrubbers.

Because of the corrosive nature of the emissions, many of the control devices require process gas pretreatment. Baghouses, when used with cupolas, usually require gas preconditioning as a result of the high temperatures associated with the cupola exhaust which may damage the bag material. Control devices used to precondition stack gases include wet caps, afterburners and quench cooling chambers. The preconditioning includes cooling and initial removal of stack gas constituents such as sparks and tars that may cause damage to the subsequent control device.

Wet caps are used to remove the larger size particulate matter and to cool the gas. The wet cap works by flooding water over an obstruction, or cap, in the path of the gas flow.

The afterburner is required to oxidize carbon monoxide and remove organic fumes, tars and oils.[3] The removal of these contaminants protects the secondary control device from potential plugging and explosions. The afterburner effluent generally requres cooling prior to entering the secondary control unit.

Quench cooling systems are often used in gray iron foundries for both gas cooling and initial cleaning.

Electric Are Furnaces

Although emission rates tend to be lower and particulate size smaller, electric are furnaces generally require the same degree of emission controls as cupolas. Emissions from electric are furnaces can be divided into three categories: Those originating from the charge materials; those generated during melting and refining; and those emitted during furnace tapping. Furnace charging and tapping emissions occur infrequently and only represent a small percentage of the total emissions. Electric arc furnace emissions are controlled by the combination of a collection system and a gas cleaning device.

Virtually all electric arc furnaces use one of six basic exhaust collection systems for control of emissions. They are: roof mounted hoods, side draft hoods, direct furnace evacuation, partial furnace enclosure, canopy hoods and total furnace enclosure. The first three systems are for the control of only the primary emissions, ie. from the melting operation. The last two systems (and to some extent the partial furnace enclosure) are able to capture both primary and secondary emissions, ie. from the melting operation as well as from charging and tapping.

The gas cleaning devices used are similar to those applied to cupolas; i.e., baghouses and high energy scrubbers. The most commonly used gas cleaning device is the baghouse. In recent years, condiserable effort has been devoted to the development of gravel bed collectors. These devices are able to clean gases in excess of 500°C, which far exceeds the temperature capability of fabric filter collectors. There is one commercially available wet collection system in use in the United States. Removal is achieved by means of steam injection at supersonic velocity into a mixing section. This unit utilizes waste process heat from an integrated iron and steel mill and would not be practical for most foundries where waste steam is not available.[41]

Electric Induction Furnaces

Induction furnaces are not a major source of emissions. Furnace charges tend to be preheated to the point that much of the emission potential is removed. The emissions that are generated are primarily iron oxide. The majority of emissions usually occur during charging, skimming and pouring.[5] Organic and metallic impurities in the scrap can cause increased emissions during charging. Emissions can be controlled during melting by keeping the furnace lid closed. Local hooding and collection systems may be used to capture furnace emissions, thus preventing their release into the work place. In general, gas cleaning equipment is not used.

Reverberatory Furnaces

Reverberatory furnaces typically do not emit significant quantities of emissions because they are normally fired with natural gas or oil. This is not true, however, when coal is used as the fuel.[5] Emissions from reverberatory furnaces are usually comprised of the charge by-products, although there is some indication that small quantities of slag and iron oxides[1] are emitted. These emissions are usually controlled, where necessary, by wet scrubbers or baghouses.

Pouring and Cooling

Hot metal pouring and cooling of molds are minor sources of particulate emissions and organic vapors. However, because the temperature and moisture content are usually sufficient to sustain combustion, the organic vapor will burn off in the mold vents.[5] Particulate emissions released from these operations are often collected by localized low-velocity, high volume hoods. Gas cleaning devices are not typically used to minimize the release of particulate matter.

Sand Handling Systems

Sand handling system include shakeout, sand preparation, and sand transfering. These systems tend to be major sources of primarily coarse particulate emissions. The emissions are usually captured by a collection system and ducted to a particulate control device. The control devices used most often are wet scrubbers. Baghouses are used when the gases are well above the dew point. The collection systems play an important role in minimizing foundry workers exposure to high free silica dust concentrations that result from the sand handling operations.

SECTION 3

GRAY IRON FOUNDRY EMISSION FACTORS

Emission factors for total particulate matter were developed for the gray iron foundry industry. Size specific emission factors have also been calculated based on cascade impactor test results. These emission factors and size distributions are presented in Tables 2a, 2b, and 3 and Figures 2 through 7. The procedures used in compiling this information, calculating the emission factors and rating the emission factors are outlined in this section.

DATA REVIEW PROCEDURES

All available sources of data were reviewed to develop the emission factors. Sources of data which reported the results of actual measurements and observations were considered primary sources. All other sources of data which referred to summarized emission data collected and reported by a different organization or author were considered secondary sources.

Only primary sources were considered suitable for calculating emission factors if substantial primary sources were available. The data review process consisted of two steps. The first step involved obtaining the emission data, and judging if the data should be designated as a primary or secondary source. If the data were judged to be secondary, an attempt was made to obtain the primary sources.

All sources of data were organized in a file for more extensive review and analysis. These sources were ranked using an A through D grading system based on data quality and reliability according to the criteria described in the manual, "Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections." Section 1 of this report includes the definitions of A, B, C and D used in the ranking system.

The data review process was conducted on 33 separate data sources. The data contained in each were used to develop an emission factor specific to that source and site. The sources are grouped by gray iron foundry processes and control device. Source category emisson factors were then calculated and rated. The ranking assigned to the emission factors reflects the rankings of the data used to develop that emission factor.

A brief summary of the relevant details of each test and the basis for the assigned rank follows.

TABLE 2a. EMISSION FACTORS FOR GRAY IRON FURNACES[a]

Process	Control device	Total particulate emission factor kg/Mg metal	Total particulate emission factor (lb/ton metal)	Emission factor rating
Cupola	Uncontrolled[b]	6.9	(13.8)	C
	Scrubber[c,d]	1.6	(3.1)	C
	Venturi Scrubber[e]	1.5	(3.0)	C
	Electrostatic precipitator[f]	0.7	(1.4)	E
	Baghouse[g]	0.4	(0.7)	C
	Single Wet Cap[h]	4.0	(8.0)	B
	Impingement scrubber[h]	2.5	(5.0)	B
	High energy scrubber[h]	0.4	(0.8)	B
Electric Arc Furnace	Uncontrolled[i]	6.3	(12.7)	C
	Baghouse	0.2	(0.4)	C
Electric Induction Furnace	Uncontrolled[k]	0.5	(0.9)	D
	Baghouse[l]	0.1	(0.2)	E
Reverberatory	Uncontrolled[m]	1.1	(2.1)	D
	Baghouse[n]	0.1	(0.2)	E

[a]Expressed as weight of pollutant per weight of gray iron produced.

[b]References 3,7,9 and 10

[c]Includes averages for wet cap and other scrubber types not already listed.

[d]References 12 and 17.

[e]References 12,23,24 and 25.

[f]References 8 and 11

[g]References 12 through 14

[h]References 8,11,38 and 39.

[i]References 3,6, and 31

[j]References 6,31 and 32.

[k]References 3 and 12

[l]Reference 5.

[m]Reference 3.

[n]Reference 5.

TABLE 2b. PARTICULATE EMISSION FACTORS FOR ANCILLARY PROCESS OPERATIONS AND FUGITIVE SOURCES AT GRAY IRON FOUNDRIES[a]

Process	Control device	Total particulate emission factor		Emission factor rating
		kg/Mg metal	(lb/ton metal)	
Scrap and charge handling, heating[b]	Uncontrolled	0.3	(0.6)	D
Magnesium treatment[c]	Uncontrolled	0.9	(1.8)	E
Inoculation[d]	Uncontrolled	1.5-2.5	(3-5)	D
Pouring and cooling[e]	Uncontrolled	2.1	(4.2)	D
Cleaning, finishing[b]	Uncontrolled	8.5	(17)	D
Shakeout[f]	Uncontrolled	1.6	(3.2)	D
Sand handling	Uncontrolled[c]	1.8[h]	(3.6)[h]	E
	Scrubber[g]	0.023[h]	(0.046)[h]	
	Venturi scrubber[i]	0.013[h]	(0.026)[h]	D
	Baghouse[i]	0.10[h]	(0.20)[h]	D
Core making, baking[b]	Uncontrolled	0.6	(1.1)	D

[a]Expressed as weight of pollutant per weight of metal melted.

[b]Reference 5.

[c]Reference 3 and 5.

[d]Reference 40.

[e]References 3 and 34

[f]Reference 5.

[g]References 12 and 37

[h]kg (lb) of pollutant per Mg (ton) of sand handled.

[i]Reference 12.

TABLE 3. SPECIFIC PARTICLE SIZE DISTRIBUTION DATA AND EMISSION FACTORS FOR GRAY IRON FOUNDRIES[a]

	Emission factor rating	Particle size (≤μm)	Cumulative mass percent less than stated size[b] (%)	Cumulative mass emission factor	
				kg/Mg metal	(lb/ton metal)
Cupola Furnace[b]					
Uncontrolled	C	0.5	44.3	3.1	(6.1)
		1.0	69.1	4.8	(9.5)
		2.0	79.6	5.5	(11.0)
		2.5	84.0	5.8	(11.6)
		5.0	90.1	6.2	(12.4)
		10.0	90.1	6.2	(12.4)
		15.0	90.6	6.3	(12.5)
			100.0	6.9	(13.8)
Controlled by Baghouse	E	0.5	83.4	0.33	(0.58)
		1.0	91.5	0.37	(0.64)
		2.0	94.2	0.38	(0.66)
		2.5	94.9	0.38	(0.66)
		5.0	94.9	0.38	(0.66)
		10.0	94.9	0.38	(0.66)
		15.0	95.0	0.38	(0.67)
			100.0	0.4	(0.7)
Controlled by Venturi Scrubber	C	0.5	56.0	0.84	(1.7)
		1.0	70.2	1.05	(2.1)
		2.0	77.4	1.16	(2.3)
		2.5	77.7	1.17	(2.3)
		5.0	77.7	1.17	(2.3)
		10.0	77.7	1.17	(2.3)
		15.0	77.7	1.17	(2.3)
			100.0	1.5	(3.0)

(continued)

TABLE 3 (continued)

	Emission factor rating	Particle size (≤μm)	Cumulative mass percent less than stated size[b] (%)	Cumulative mass emission factor	
				kg/Mg metal	(lb/ton metal)
Electric Arc Furnace[d] Uncontrolled	E	1.0	13.0	0.8	(1.6)
		2.0	57.5	3.6	(7.2)
		5.0	82.0	5.2	(10.3)
		10.0	90.0	5.7	(11.3)
		15.0	93.5	5.9	(11.8)
			100.0	6.3	(12.7)
Pouring and cooling[b] Uncontrolled	D	0.5	[e]	-	-
		1.0	19.0	0.40	(0.80)
		2.0	20.0	0.42	(0.84)
		2.5	24.0	0.50	(1.00)
		5.0	34.0	0.71	(1.42)
		10.0	49.0	1.03	(2.06)
		15.0	72.0	1.51	(3.02)
			100.0	2.1	(4.2)
Shakeout[b] Uncontrolled	E	0.5	23.0	0.37	(0.74)
		1.0	37.0	0.59	(1.18)
		2.0	41.0	0.66	(1.31)
		2.5	42.0	0.67	(1.34)
		5.0	44.0	0.70	(1.41)
		10.0	70.0	1.12	(2.24)
		15.0	99.9	1.6	(3.2)
			100.0	1.6	(3.2)

[a]Expressed as weight of pollutant per weight of metal melted.
[b]References 13, 14, 27, 18, 34, 35, and 37 as listed in Figures 14-19.
[c]Based on operational pressure drop of approximately 260 cm W,C, across venturi-rod bed.
[d]References 2 and 3. Exhibit VI-15 of Reference 3, average of Foundry B and C data. Because the original test data could not be obtained, and emission factor rating of E was assigned to this category. No mass emission rate data were available to calculate size specific emission factors.
[e]No data.

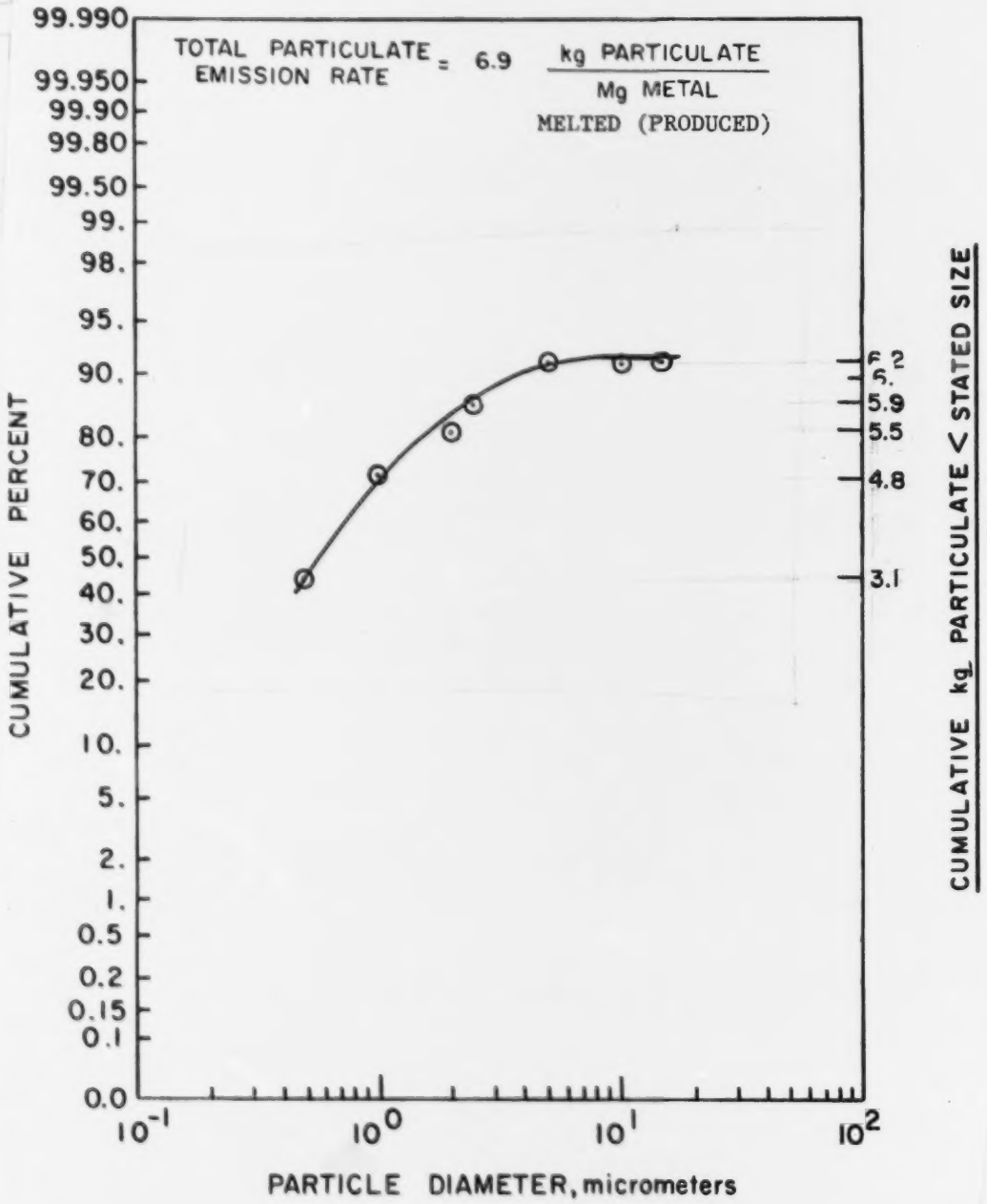

Figure 2. Uncontrolled cupola particle size distribution.[27,28]

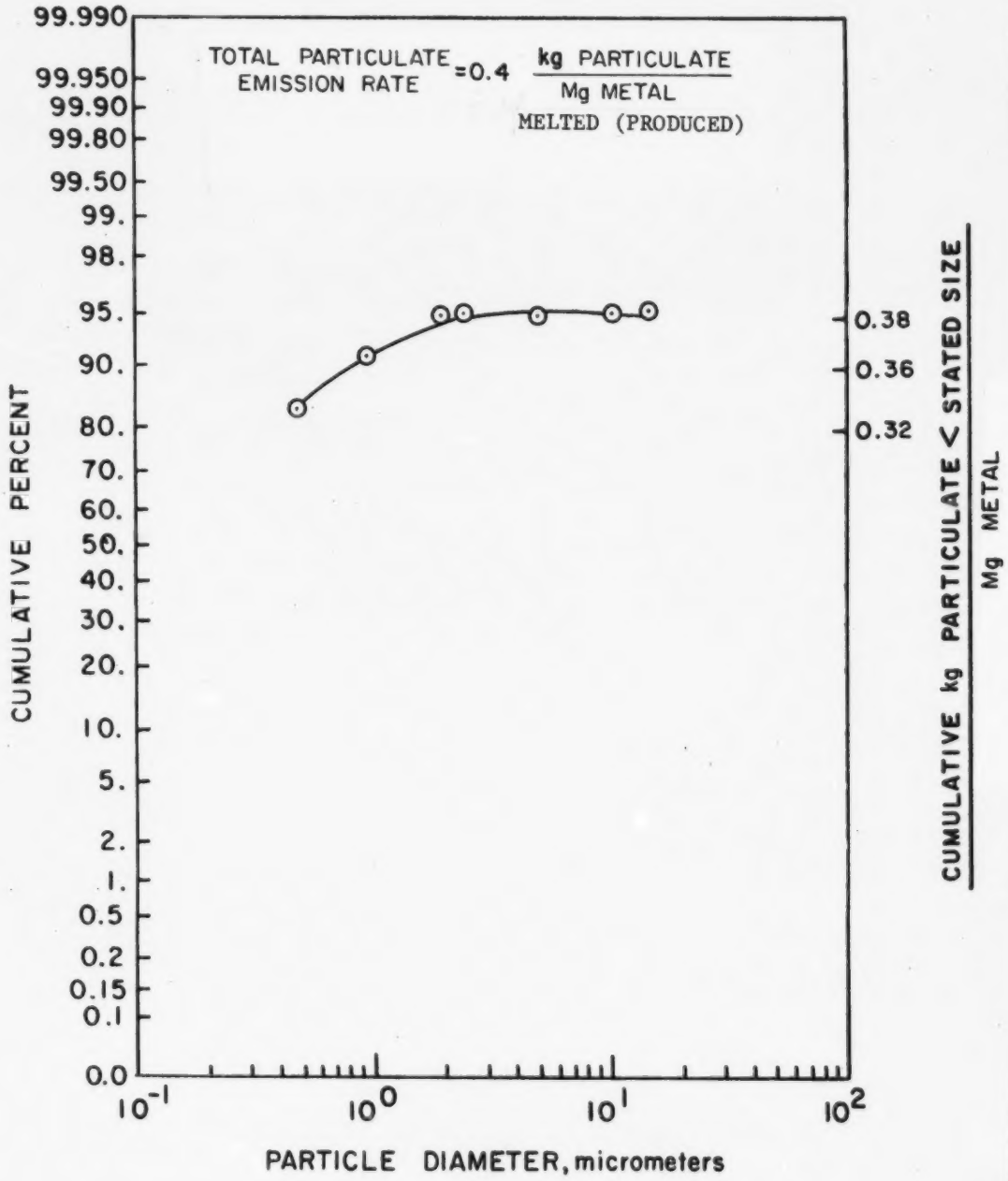

Figure 3. Controlled (baghouse) cupola particle size distribution.[13,14]

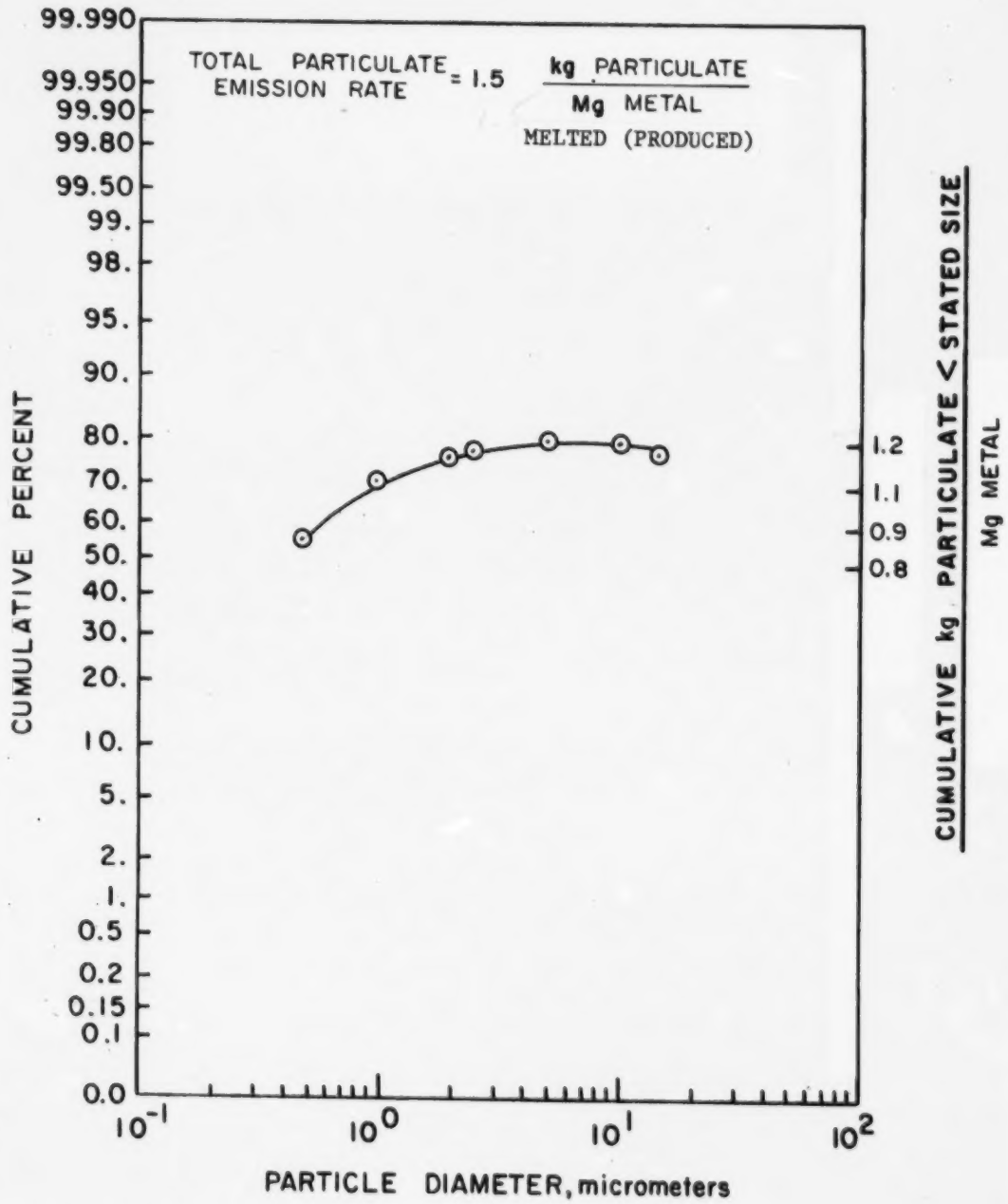

Figure 4. Controlled (venturi scrubber) cupola particle size distribution.[27,28]

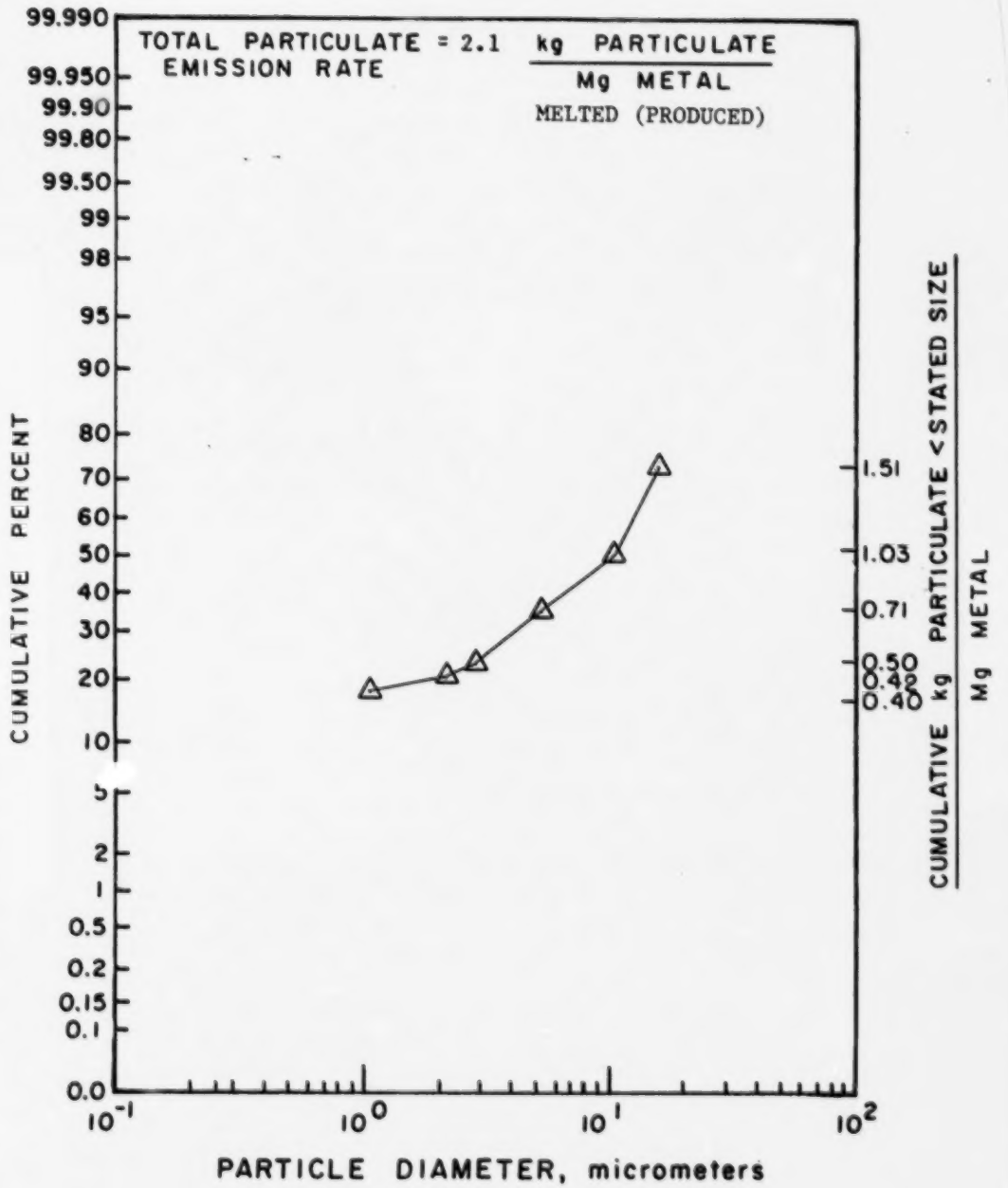

Figure 5. Uncontrolled pouring and cooling emissions--particle size distribution.[34]

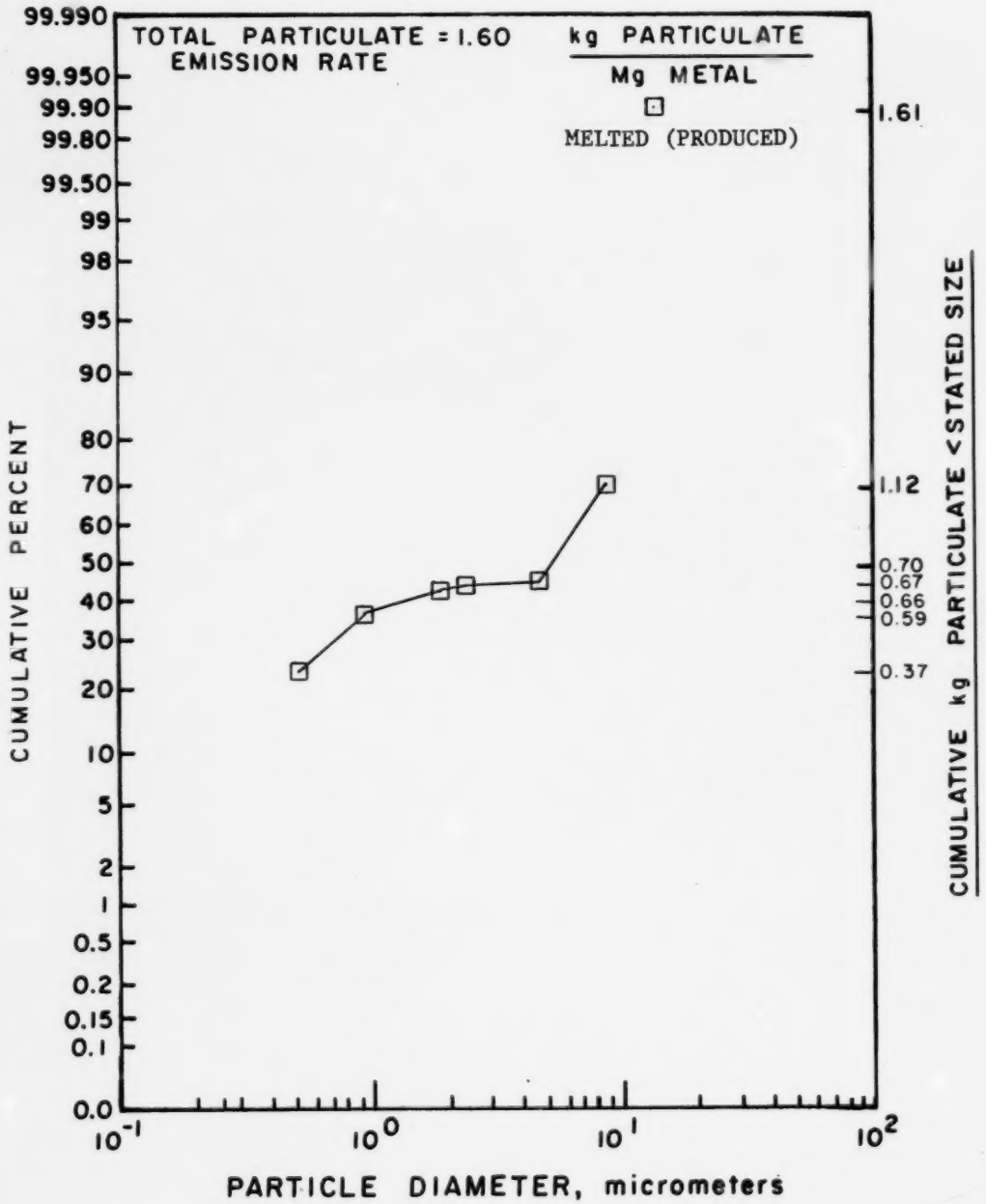

Figure 6 . Uncontrolled shakeout emissions--particle size distribution.

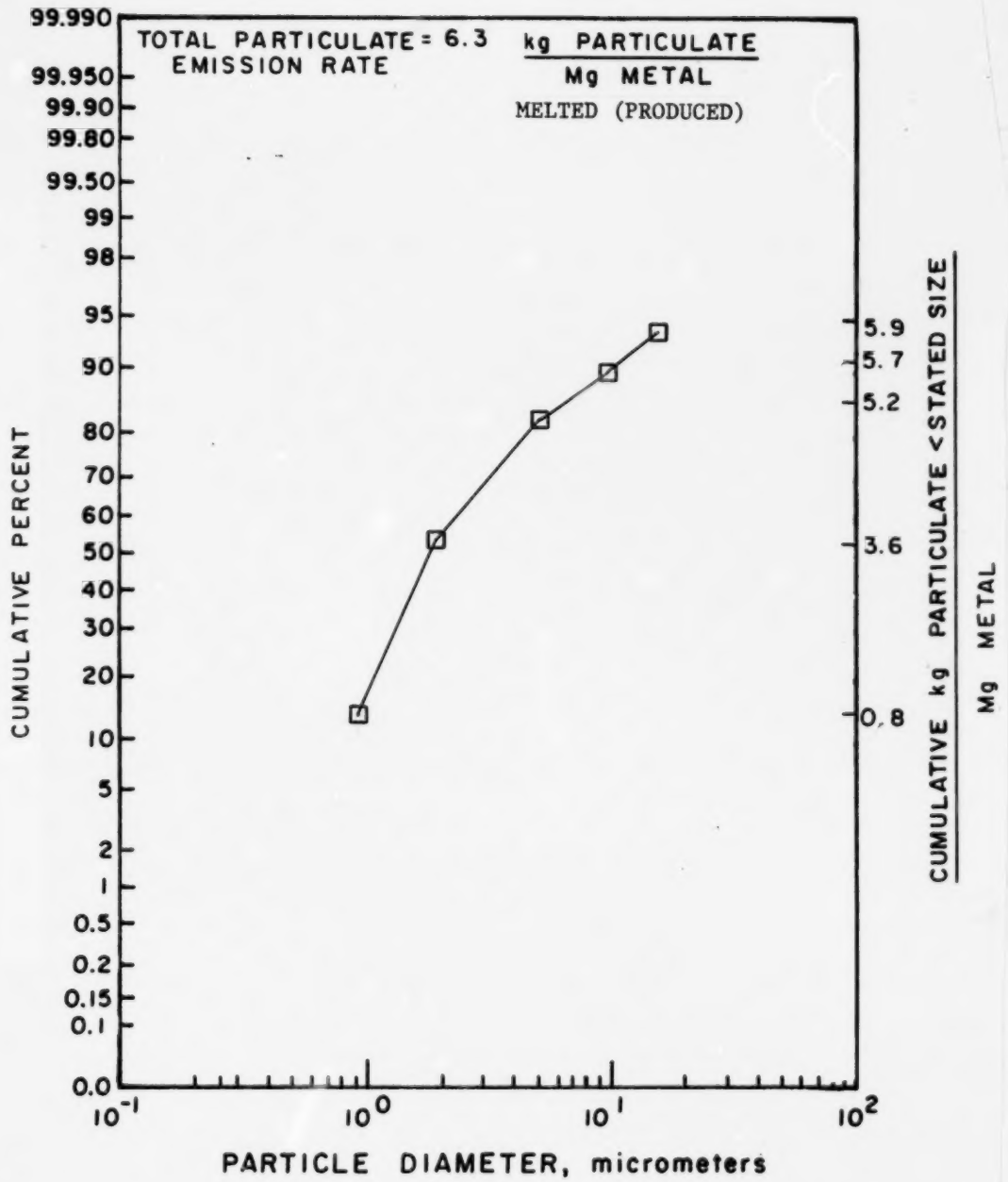

Figure 7. Uncontrolled electric arc furnace particle size distribution.[2,3]

RANKING OF TEST DATA FOR GRAY IRON FOUNDRY PROCESSES

General Foundries

Information source No. 3 was a Midwest Research Institute (MRI) report entitled "Summary of Factors Affecting Compliance by Ferrous Foundries".[3] The data presented were reduced data collected from each gray iron foundry process. Normally this report would be considered as a secondary source, however, the reduced data were given a high reliability factor by MRI. This factor was modified for integration into this report. All A and B MRI ranked data were ranked B for this revision of AP-42. These data were given a high reliability rating by MRI, and are assumed to be quality data. The MRI rankings of C - E were ranked D in this report. MRI considered these as engineering estimates or unsubstantiated data.

Source No. 5 was a Battelle Laboratories report.[5] This source was designated a secondary source since data from this report were collected from a number of sources. These data could not be verified or substantiated since only reduced data were reported and no ratings were supplied by Battelle. Data were, therefore, rated D.

Source No. 6 was a report including the testing of five facilities (A-E).[6] Each of these facilities (A-E) was an electric arc furnace with baghouses as control devices. The testing was conducted by EPA utilizing EPA Methods 1-5. Individual report characteristics are detailed below. The data for each source were rated B.

Source 6-A was a foundry with three electric arc furnaces, controlled by two baghouses.[6] Each furnace had a melt capacity in the range of 7.5 to 8 Mg (15 to 16 tons). The baghouse controlled all EAF emissions that were collected by side draft hoods, pouring spout and slag door hoods. The furnaces are rated at a maximum of 8 Mg (16 tons) per charge. Particulate (EPA Methods 1-5) testing was performed at the inlet (uncontrolled) and outlet (controlled) locations of the baghouse. These tests were performed during the period of June 18-20, 1974.

Source 6-B was a foundry with four electric arc furnaces.[6] Each furnace had a melt capacity in the range of 6 to 6.5 Mg (12 to 13 tons) and emissions were controlled by two baghouses. These baghouses control emissions which were collected by side draft hoods, and pouring spout and slag door hoods. Particulate sampling (EPA Methods 1-5) at the baghouse outlet was performed during the period of June 8-9, 1974.

Source 6-C was a foundry with two electric arc furnaces.[6] Each furnace was rated at 4 Mg (8 tons) per heat. The emissions were collected by a roof hood and pouring spout and slag door hoods. Particulate tests (EPA Methods 1-5) were performed on September 18-19, 1974, on the baghouse outlet.

Source 6-D had a single electric arc furnace.[6] The furnace had a melt capacity of 3 Mg (6 tons). The emissions were collected by a side draft hood and pouring spout and slag door hoods. Particulate testing was performed on January 1-3, 1974. These tests were performed on both the inlet and outlet of the baghouse.

Source 6-E had a single electric arc furnace.[6] This furnace had a production capacity of 7 Mg (14 tons) of metal per heat. The furnace emissions were collected by a side draft hood and pouring spout and slag door hoods. Particulate testing was performed on May 5-7, 1974 at the baghouse outlet only.

Cupolas

Source No. 7 data were presented in a report covering three iron foundries.[7] These iron foundries were tested as a preliminary study for installation of a flux force condensation control device. Particle size testing was performed for this study at the three foundries.

The first site was a cupola with an internal diameter of .94m (3.1 ft) and a melting rate of 1.5 Mg/hr (3 tons/hr). The furnace produced gray iron castings for use in shipbuilding.

The second site was a cast iron pipe and fitting company. The cupola had a internal diameter of 1.67m (5.5 ft) and a melting rate of 5.7 Mg/hr (11.3 tons/hr).

The third site was a foundry that produced metal shot. The internal diameter of the cupola was 1.67m (5.5 ft). The maximum normal production rate was 7.4 Mg/hr (14.9 tons/hr).

The particle size testing was performed by Air Pollution Technology Inc. using University of Washington impactors. In order to determine particle concentration and mass flow rate, EPA Method 5 runs were performed. All testing was performed after a spray quencher but before any control devices. These emissions were referred to as uncontrolled.

The particle sizing data were presented as a preface to the major work on the force flux condensation scrubber. The particle size data and total particulate data were therefore rated B.

Source No. 8 data were generated during the development of emissions factors by the Los Angeles Air Pollution Control District.[8] Included were emission factors for cupolas that were uncontrolled and those controlled with ESPs or baghouses. The data lack any substantiation or description and are considered a secondary source. The data were rated D.

Source No. 9 was a report of tests at a gray iron cupola used for producing municipal castings.[9] EPA Method 1-5 testing was performed on uncontrolled emissions. There were no fluxing agents used in the melt.

Process data were provided in the report.[9] The furnace charges were presented detailing the charge composition in both pounds of metal and pounds of coke per hour. This information was used to calculate the emissions on a lb/ton metal basis. The testing was performed on December 8, 1975, and January 2 and 15, 1976. The report was rated B.

Source No. 10 was a report of testing on 10 cupolas during 1976-1977 for a Doctorate thesis at Pennsylvania State University.[10] The cupolas tested were well described. The information contained in this report was complete, although some of the information needed, such as size specific emission factors, was either not easily available or unavailable. Nonetheless, all useful data were taken out of this report and utilized.

Particle size distributions were presented graphically in the report.[10] The determination of particulate emissions concentrations based on lb/ton metal required reducing various data available such as the graphs and the emissions that were given as a Kg/MTMC (kilogram/Metric Ton-Metal Cast) for particles less than 10 micrometers. The particle sizing data were rated B. The resultant data used were reduced data from numerous runs.

Source No. 11 was U.S EPA Air Pollution Engineering Manual.[11] The data used lacked substantiation, since only reduced summaries were available. This was considered a secondary source. These data were rated D.

Source No. 12 was a report of tests at several sites[12] performed for the Wisconsin Department of Natural Resources. Although the original test reports were not available, information such as process weight rate, emission rates, types of units and types of control devices was presented as a synopsis. These reports have individually been rated B, since both the reported information, and information made available during telephone conversations was complete. All particulate testing was performed using EPA Methods 1-5.

Source 12A was the #5 gray iron cupola at Barclay Foundry Industries, Milwaukee, WI.[12] The cupola was a 127 cm (50 in.) diameter, water jacketed cupola, with an operating capacity of 3 Mg/hr (6 tons/hr). The emissions were controlled by a baghouse preceeded by a cooling tower. The cooling tower was used for temperature protection for the baghouse. Particulate tests were performed on January 19-20, 1977.

Source 12B was the #6 gray iron cupola at Alpha Cast, Inc., Whitewater, WI.[12] Particulate tests were performed on January 10, 14, 15, 1980. The cupola had an average melt rate of 4 Mg/hr (8 tons/hr). The emissions were controlled by a wetcap and afterburner.

Source 12C was the #4 gray iron cupola at M&M Gray Iron Foundry, Waupun, WI.[12] The cupola was 32 in. in diameter with an average melt rate of 2.3 Mg/hr (4.6 tons/hr). The emissions were controlled by a wet scrubber followed by a spray chamber with baffles. Particulate emissions tests were performed during the period June 24-26, 1980.

Source 12D was the #6 cupola at Iroquois Foundry, Browntown, WI.[12] The cupola is 122 cm (48 in.) in diameter with an 4 Mg/hr (8 ton/hr) capacity. The emissions were controlled by a scrubber. The testing was performed on January 12, 1979.

Source 12E was a cupola at Motor Castings Co., West Allis, WI[12] and was rated at 5.5 Mg/hr (11 tons/hr). The emissions were controlled by a scrubber. Particulate tests were performed on July 21 and 22, 1977.

Source 12F was a cupola at Falls Foundry, Menomonee Falls, WI.[12] The cupola was 107 cm (42 in.) in diameter and emissions were controlled by a wet scrubber. The maximum melt rate was 3.6 Mg/hr (7.2 tons/hr). Particulate tests were conducted during August 5-7, 1975.

Source 12G was a cupola at Kirsh Foundry, Beaver Dam, WI.[12] The normal operating rate for this facility was 2.5 Mg/hr (5 tons/hr). Two series of particulate tests were performed, one with cleaned and one with uncleaned scrap. The emissions were controlled by a Schneible wet cap. The tests were conducted on May 15-17, 1978.

Source 12H was the #5 cupola at Sharon Foundry, Sharon, WI.[12] The cupola had a melt rate about 3.7 Mg/hr (7.4 tons/hr). The emissions were controlled by a venturi scrubber followed by a demister. The testing was performed on November 24-25, 1980.

Source 12I was the #6 cupola at Pioneer Foundry, Milwaukee, WI.[12] The cupola was 122 cm (48 in.) in diameter and had a melt capacity of 4.5 Mg/hr (9 tons/hr). The emissions were controlled by a venturi scrubber. Particulate testing was performed on October 18 and 20, 1976.

Source 12J was a cupola at Neenah Foundry Co., Neenah, WI.[12] The cupola had a 152 cm (60 in.) inside diameter and was controlled by a venturi scrubber. Particulate testing was performed on September 4, 1974. This cupola had an average melt rate of 7.4 Mg/hr (14.7 tons/hr). Another cupola at the same facility was tested on August 23, 1977. This cupola had a 157 cm (62 in.) diameter with an average melt rate of 7.5 Mg/hr (15 tons/hr). The emissions were controlled by an Kinpactor venturi scrubber.

Source 12K was a cupola at Beloit Corporation, Beloit, WI.[12] The cupola was 168 cm (66 in.) in diameter and rated between 7.5-11 Mg/hr (15-22 tons/hr). The source emissions were controlled by a wet cap followed by a Kinpactor venturi scrubber. The particulate tests were performed on September 16 and 17, 1975.

Source 12L was a cupola at Waupaca Foundry, Waupaca, WI.[12] The cupola had a design capacity of 4-5 Mg/hr (8-10 tons/hr). The emissions were controlled by a venturi scrubber. Particulate tests were performed on February 9, 1977.

Source 12M was an induction furnace at International Harvester, Waukesha, WI. The testing was performed on September 15, 1981.[12] The testing was performed on a canopy hood evacuation system with no control device. Emissions from three induction furnaces, a holding furnace and a desulfurization process were combined. The entire operation operates with a process weight rate of 5.5 Mg/hr (11 tons/hr).

Source 12N was a sand-handling system at Grede Foundry-Liberty Plant, Wauwatosa, WI.[12] The emissions were from a molding line, a shakeout, a sand mixer and sand handling system. The process rate for the molding line was 2.5 Mg/hr (5 tons/hr) sand plus metal. The emissions were controlled by a scrubber. Three particulate test runs were conducted on August 6, 1981.

Source 12-O was a sand handling system at the Milwaukee Malleable and Gray Iron Works. The emissions were controlled by a venturi scrubber.[12] The process weight is normally 30 Mg/hr (60 tons/hr). Particulate testing was performed on July 23, 1979.

Source 12P was a Muller system and shakeout system at Mid City Foundry, Milwaukee, WI. These sand handling systems had a maximum process rate of 6 Mg/hr (12 tons/hr). The emissions were controlled by a venturi rod scrubber. The tests were performed on August 7 and 8, 1975.

Source 12Q was a gray iron foundry at Briggs and Stratton, West Allis, WI.[12] The tests were performed on September 4, 1980. The testing was performed on the molding process which handled approximately 33.5 Mg/hr (67 tons/hr) during testing. This included the sand handling system, twin molding lines and shakeout. The emissions were controlled by a baghouse; this is the only source report acquired with a sand handling system controlled this way.

Source No. 13 was a report of tests on the #3 cupola facility at Opelika Foundry, Opelika, AL.[13] The emissions were controlled by an afterburner, quench tower and baghouse. The testing consisted of both particle size and particulate testing at the outlet of the baghouse. The particulate testing was conducted in accordance with EPA Methods 1-5 on November 30, 1977. The particle sizing was conducted using Andersen Mark III impactors under isokinetic conditions on January 4, 1978.

The report provides an average composition of the charge. This composition was used to determine the charge weight of metal. The report did not include a process weight during particle sizing tests so it was assumed to be the same as the process weight during total particulate testing. The particulate testing was rated B. The particle size data were rated C.

Source No. 14 was a report containing results from a series of three tests conducted at three separate sites in Minnesota.[14] All particulate testings were conducted in accordance with EPA Methods 1-5.

Source 14A was the #4 cupola at Acme Foundry Co., Minneapolis, MN. The cupola was designed to handle a maximum of 3 Mg/hr (6.0 tons/hr).[14] The emissions were controlled by a baghouse. Particulate tests were performed on January 15, 1982. The data were rated C.

Source 14B was the #3 1/2 cupola at Carter Day Co., Minneapolis, MN. The cupola has a melt rate of 1.2 Mg/hr (2.3 tons/hr).[14] The emissions were controlled by a baghouse. Particulate testing was performed on August 20, 1979. The data were rated C.

Source 14C was the #4 cupola at Central Castings Corporation, Minneapolis, MN.[14] The emissions were controlled by a baghouse. Particulate testing was performed on May 29, 1980. The data were rated C.

Source No. 15 was a report of tests conducted at Flynn and Enrich Co., Baltimore, Maryland during November of 1975.[15] Particulate testing was performed on a gray iron cupola according to standard Maryland State Bureau of Air Quality and Noise Control particulate stack testing procedures, as outlined in BAQNC technical memorandum 73-116. The emissions were controlled by a quench spray system, cyclones and an afterburner. This system did not pass the applicable state air pollution regulations. The furnace coke bed was comprised of coke, wood, and paper. The wood and paper were used to ignite and heat the bed.

The first test had an unexplained variation in both stack temperature and fixed gas composition. The report included a production rate which was inferred to be a metal production rate. The data were rated C.

Source No. 16 was a report of tests conducted at Frederick Iron and Steel, Frederick, Maryland during November, 1977.[16] The furnace was controlled by a wet cap and venturi. The report summarizes results of three tests. With the exception of the percent moisture in the stack the tests were conducted in accordance with standard Maryland State Bureau of Air Quality and Noise Control stack testing procedures, as outlined in BAQNC technical memorandum 73-116. The report described the process rate which was inferred to be a production rate. The data were rated C.

Source No. 17 was a report of tests on the cupola at Dunkirk Radiator Corporation, Dunkirk, NY.[17] The emissions were controlled by a high energy wet scrubber. Particulate tests were performed on November 6-12, 1975 in accordance with EPA Methods 1-5. The report contained an adequate description of the process and sampling system designs, and a detailing of the charge composition. The data were rated B.

Source No. 18 was a report of tests on the cupola at Dewey Brothers, Goldsboro, NC.[18] The source was controlled by a scrubber. The cupola was designed for a peak process rate of 7.1 Mg/hr (14.2 tons/hr). Whereas two reports were provided, only one was used. The first of the two, performed on August 30, 1977, did not properly identify the process weight during testing. This report was not used. The second report, performed on April 7, 1978, provided the production rate during testing and the emissions based on lb/ton product. Sampling was done in accordance with EPA Method 1-5. Neither report was in compliance with State emission limits. The April 7, 1978 data were rated a C.

Source No. 19 was a report of tests on the cupola at Stovall's Foundry, Gastonia, NC.[19] The source was controlled by a prototype self-aspirating scrubber. The cupola was designed for 2.5 Mg/hr (5 tons/hr). There was little information detailing occurrences during the tests which were performed according to EPA Method 5. Modifications were performed that distinguish the two test series, but no data documenting the difference were available. The only data provided to describe the differences were particulate data. The data were rated C.

Source No. 20 was a report of tests on the #11 cupola at Newman Foundry, Kendallville, IN.[20] The emissions were controlled by a scrubber. Particulate tests were performed on June 11, 1974. There is not much information given with this report, however it states that the cupola is in compliance with the State of Indiana Air Pollution Control Regulation APC-5. Thus the tests were most likely conducted in accordance with EPA Method 5. The report was rated C.

Source No. 21 was a report of tests on a cupola at the Swaine Robinson Co., Richmond, Indiana.[21] The emissions were controlled by a venturi scrubber, preceded by a quench chamber. The test had no description of the sampling method. There was very little information describing the process. The text included a description of a typical charge. This description was used to develop a metal to charge ratio to convert the process weight rate from tons total charge to tons of metal charged. The data were rated C.

Source No. 22 was a test report for the cupola at Sterling Castings Corporation, Bluffton, Indiana.[22] The cupola emissions were controlled by a quench chamber followed by a venturi rod scrubber. The report detailed the typical charge composition, and total weight of charged material during testing. Particulate testing was performed on February 8-9, 1977. There is no description of the tests that were performed. The data were rated C.

Source No. 23 was a report of tests on a No. 9-1/2 gray iron cupola at Worthington Corporation, Buffalo, NY.[23] The cupola emissions were controlled by a Kinpactor venturi scrubber. The cupola has an average design charge weight of 11.5 Mg/hr (23 tons/hr). The report had a good description of both tests and unit operation during the sampling period. A description of the charge composition was provided for each run, and was used to compute a process weight rate. The tests were conducted in accordance with EPA Method 5. The data were rated B.

Source No. 24 was a report of tests performed on a cupola at the Dresser Clark plant in Orlean, NY.[24] The testing was performed on July 14 and 18, 1977. The cupola emissions were controlled by a venturi scrubber. The scrubber was preceded by an afterburner and quenching system, and was followed by a demister. Three particulate tests were performed according to EPA Method 5 to determine compliance with New York State emission requirements. The process weight rate used was an average of the daily rate. Two average weight rates were determined, one for each day of sampling. The specific composition of each cupola charge was described. There is only a limited description of the source. The data were rated B.

Source No. 25 was a report of tests on two iron cupolas at Chevrolet's Tonawanda plant in Tonawanda, N.Y.[25] The emissions were controlled by individual systems consisting of a quench system, venturi scrubber and a demister. One of the cupolas did not have a quench system. Particulate tests were performed on each of these control systems according to EPA Method 5 procedures on August 9-16, 1977. The report includes a general description of the charge composition. The data were given a B rating.

Source No. 26 was a report of tests on an iron cupola at Atlantic States Cast Iron Pipe Co., Phillipsburg, NJ.[26] The source was controlled by a venturi scrubber. The report gave no description of testing conditions or process operations. The process weight rate was given as raw material charged and the testing was conducted according to EPA Method 5 procedures. The data were rated C.

Source No. 27 was a report detailing the testing of fine particle collection efficiency of scrubbers.[27] This report detailed nine sites, one of which was an iron foundry. The particle size emission data were complete and reduced. The results of nine inlet and outlet tests were reduced and used in the calculation of specific emission factors. The report was written to detail the scrubber efficiencies, and therefore the source description was minimal. The control device was a venturi scrubber. The particle size data were rated B.

Source No. 28 was a report detailing the efficiency of a variable rod venturi scrubber.[28] This report described the control device and sampling methods. Since the cupola design had minimal impact on the venturi operation, the cupola design was not discussed in any great detail. The particle size sampling was performed with University of Washington impactors. Seventeen outlet and 16 inlet runs were conducted. The results of these runs were reduced and the resultant averages were used in the calculation of specific emission factors. The particle size data were rated B.

Source No. 29 was a report of tests on a gray iron cupola. The emissions were controlled by a gas atomized spray scrubber.[29] This scrubber was generically referred to as a venturi scrubber, based on the variable throat design specifications. Particle size sampling was performed using University of Washington impactors. Fifteen inlet and outlet runs were conducted and the resultant two averages used in the calculation of specific emission factors. The particle size data were rated B.

Electric Arc Furnaces

Source No. 30 provided emissions data for 19 different EAFs.[30] This information was used to develop the average EAF emission rate for the original AP-42. Although it is a secondary data source, it is assumed to be representative of electric arc furnace emissions. The data were rated C.

Source No. 31 was a report of tests conducted at the Paxton-Mitchell Foundry, Omaha, Nebraska, during the period of September 29 - October 4, 1974.[31] The foundry consisted of an electric arc furnace with a baghouse controlling emissions. Total particulate testing was performed, according to EPA Method 5, before and after the baghouse. Furnace evacuation was accomplished by a side draft hood, spout-pouring hood and slag door hood. The data were given a B rating. Although the report contained substantial information, a description of the process operation during the test period was missing. This information was referenced in the report as an appendix, which

was not readily available. The data from two runs were not included in the calculated emission factor; one for an inlet location due to non-isokinetic sampling and one at the outlet due to "observed" broken bags in the baghouse.

Source No. 32 was a report of tests at an electric arc furnace at John Deere Tractor Works, East Moline, IL on July 8 and 9, 1974.[32] The tests were performed on emissions from a baghouse controlling two swinging roof electric arc furnaces. Each furnace was designed to produce 5.5 to 6.5 Mg (11 to 13 tons) of iron per heat. These furnaces were 3.3 meters (11 ft) in diameter. The composition of the individual charges was included on process log sheets. The report detailed six Method 5 tests that were performed in addition to hydrocarbons, SO_x, NO_x and visible emissions. The process weight rate was determined by reducing the data provided on process log sheets. The data were rated A.

Induction Furnaces

Source No. 33 was a British translation of a German report on emissions from uncontrolled induction furnaces.[33] The emission data were obtained at three foundries. Information regarding the furnace operation and testing methodologies were not included. An assumption was made in determining the reported emission rate. It was assumed that the designed melt rate is the process weight rate of metal added. Accordingly, the data were rated C.

Pouring and Cooling

Source No. 34 was a report detailing pouring and cooling emissions from the Archer Creek Plant of Lynchburg Foundry, Lynchburg, VA.[34] The foundry uses two pouring and cooling lines and emissions are vented uncontrolled through six stacks, three for each process. The foundry produces 75,000 Mg (150,000 tons) per year, of which 75 percent is ductile iron and 25 percent is mostly gray iron castings.

The testing was performed to characterize inhalable particulates. Total particulate (Method 5) sampling, dual cyclone, and impactor sampling were performed.

The process operations and sampling methods were well detailed and the production weight rate was well documented. The particle size and particulate data were rated A.

Sand Processes

Source No. 35 was a report containing test information regarding emissions from two casting and shakeout operations at United States Pipe and Foundry, Anniston, AL.[35] The emissions from the first process were controlled by a rotoclone scrubber. The emissions for the second process were uncontrolled. The tests were performed on November 6-7, 1973. The report contains a good process description, but has no information regarding the testing that was performed. The data from both locations were rated C.

Source No. 36 was a report of tests conducted at Wheland Foundry, Chattanooga, TN on April 12, 1978.[36] Three Method 5 tests were performed on the emissions from the muller operation. The muller operation emissions were controlled by a rotoclone scrubber. There was a good description of the testing performed and the process operation itself. The data were rated B.

Source No. 37 was a report of tests on a sand handling system at Newbury Manufacturing, Talladega, AL.[37] The emissions were controlled by a rotoclone scrubber. Particulate tests were performed on May 15-16, 1979. The report did not detail the process operations during testing, and the production rate was given as an average over the entire sampling period. However, information was provided for the production rates based both on metal and sand usage. The data were rated B.

EMISSION FACTOR CALCULATION

Emission factors have been calculated according to prescribed AP-42 methodology. This methodology utilizes best available data. The preceding information describes data quality ranking methodologies and presents best available emissions data. This subsection provides a description of the calculated emission factors and particle size distribution data previously presented in Tables 2a, 2b, and 3 and Figures 2 through 7.

The tabulated data (Tables 4 through 21) have been used to calculate the revised AP-42 emission factors previously presented in Tables 2a and 2b. The tabulated data were reduced following the procedures described in "Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections." These procedures dictate that data be strictly segregated according to data quality rankings. A or B rated data are not, as required by these procedures, allowed to be combined with C or D rated data. In circumstances where various ranked emissions data were available, the highest rated data were always used.

The data presented in many of these sources were not entirely appropriate for emission factor calculation. In these situations a decision was made whether the available data could be adapted or whether it should be excluded. The only assumptions that were used to adapt data were those that were made from information contained in the report.

TOTAL PARTICULATE EMISSION FACTOR CALCULATION

All the source data used in the total particulate emission factor calculation presented the data in pounds per hour of particulate matter. The following equation was used to calculate a total particulate emission factor in pounds per ton of metal melted:

$$E_F \text{ (lbs/ton)} = E_F \text{ (lbs/hr)} \; / \; \text{Process Rate (ton/hr)}$$

to convert to metric (kg/Mg):

$$E_F \text{ (kg/Mg)} = E_F \text{ (lb/ton)} \times \frac{4.536 \times 10^{-1} \text{ (kg/lb)}}{9.078 \times 10^{-1} \text{ (Mg/ton)}}$$

After the emission factors are calculated, a straight arithmetic mean for each process is taken as prescribed.

TABLE 4. PARTICULATE EMISSION FACTOR: CUPOLA--UNCONTROLLED

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
3	B	10.0	(20.0[a])	
7	B	3.3	(6.5[b])	Avg. of 3 sites
8	D	7.9	(15.9[c])	Avg. of 15 sites. Not used to calculate final emission factor.
9	B	4.4	(8.9[d])	
10	B	9.8	(19.7[e])	Avg. of seven sites. Particle size data also available.
11	D	6.1	(12.3[f])	Avg. of 2 runs not used to calculate final emissions factor.
Avg.	(C)	6.9	(13.8)	

[a]Reference 3.

[b]Reference 7.

[c]Reference 8.

[d]Reference 9.

[e]Reference 10.

[f]Reference 11.

TABLE 5. PARTICULATE EMISSION FACTOR: CUPOLA--WITH BAGHOUSE

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
8	D	0.36	(0.73[a])	Not used to calculate final emission factor
11	D	0.24	(0.49[b])	Not used to calculate final emission factor
12A	B	0.13	(0.27[c])	Barclay Foundry
13	B	0.77	(1.54[d])	Particle size data available
14A	C	0.03	(0.07[e])	Acme Foundry. Not used to calculate final emission factor
14B	B	0.24	(0.49[e])	Carter Day Company
14C	B	0.22	(0.45[e])	Central Casting Corp.
Avg.	(C)	0.34	(0.69)	

[a]Reference 8.

[b]Reference 11.

[c]Reference 12.

[d]Reference 13.

[e]Reference 14.

TABLE 6. PARTICULATE EMISSION FACTOR: CUPOLA--WITH ESP

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
8	D	0.51	(1.02)	Avg. of 5 sites
11	D	0.90	(1.81)	
Avg.	(E)	0.71	(1.42)	

[a]Reference 8.

[b]Reference 11.

TABLE 7. PARTICULATE EMISSION FACTOR: CUPOLA--WITH SCRUBBER (ALL TYPES EXCEPT VENTURI)

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
12B	B	1.98	(3.96[a])	Wet Cap and Afterburners
12C	B	2.52	(5.05[a])	
12D	B	0.35	(0.71[a])	
12E	B	1.81	(3.62[a])	
12F	B	2.25	(4.51[a])	Schneible Wet Cap
12G	B	1.45	(2.90[a])	Schneible Wet Cap
15	C	6.60	(13.2[b])	Wet cap and afterburner--wood ignition--Avg. of 3 runs. Not used to calculate final emission factor
17	B	0.47	(0.94[c])	
18	C	2.12	(4.24[d])	Not used to calculate final emission factor
19	C	0.63	(1.26[e])	Prototype Self-aspirating Scrubber. Not used to calculate final emission factor
20	C	0.30	(0.61[f])	Not used to calculate final emission factor
Avg.	(C)	1.55	(3.10)	

[a]Reference 12.

[b]Reference 15.

[c]Reference 17.

[d]Reference 18.

[e]Reference 19.

[f]Reference 20.

TABLE 8. PARTICULATE EMISSION FACTOR: CUPOLA--WITH VENTURI SCRUBBER

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
12H	B	2.58	(5.17[a])	
12I	B	2.59	(5.19[a])	
12J	B	1.62	(3.24[a])	
12J	B	1.69	(3.38[a])	
12K	B	1.75	(3.50[a])	Kinpactor and Wet Cap
12L	B	0.43	(0.86[a])	
16	C	0.73	(1.46[b])	Average of 3 runs. Not used to calculate final emission factor
21	C	1.18	(2.37[c])	Average of 3 runs. Not used to calculate final emission factor
22	C	0.38	(0.77[d])	Average of 3 runs. Not used to calculate final emission factor
23	B	2.17	(4.35[e])	
24	B	0.37	(0.75[f])	Average of 3 runs
25	B	0.44	(0.88[g])	
26	C	0.17	(0.35[h])	Not used to calculate final emission factor
Avg.	(C)	1.52	(3.04)	

[a]Reference 12.
[b]Reference 16.
[c]Reference 21.
[d]Reference 22.
[e]Reference 23.
[f]Reference 24.
[g]Reference 25.
[h]Reference 26.

TABLE 9. PARTICULATE EMISSION FACTOR: ELECTRIC ARC FURNACE--UNCONTROLLED

Source No.	Rating	kg/Mg metal	(lb/ton/metal)	Comments
3	B	7.0	(14.0[a])	
6A	B	3.1	(6.3[b])	
6D	B	6.4	(12.9[b])	
30	C	6.9	(13.8[c])	Avg. of 19 sites (lb/ton charge) Not used to calculate average emission factor.
31	B	8.7	(17.5[d])	Avg. of 3 runs - controlled emission factor also available.
Avg.	(C)	6.3	(12.7)	

[a]Reference 3.

[b]Reference 6.

[c]Reference 30.

[d]Reference 31.

TABLE 10. PARTICULATE EMISSION FACTOR: ELECTRIC ARC FURNACE--WITH BAGHOUSE

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
6A	B	0.07	(0.15[a])	
6B	B	0.10	(0.20[a])	Testing during lancing
6C	B	0.57	(1.15[a])	
6D	B	0.10	(0.21[a])	
6E	B	0.17	(0.35[a])	
31	B	0.18	(0.37[b])	Avg. of 3 runs - Uncontrolled emissions also available
32	A	0.04	(0.08[c])	Oil removed from foundry returns
Avg.	(C)	0.18	(0.36)	

[a]Reference 6.

[b]Reference 31.

[c]Reference 32.

TABLE 11. PARTICULATE EMISSION FACTOR: INDUCTION FURNACE--UNCONTROLLED

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
3	B	0.5	(1.0[a])	
5	D	0.75	(1.5[b])	Avg. of 3 furnaces Not used to calculate final emission factor
12M	B	0.41	(0.82[c])	
33	C	2.75	(5.51[d])	Not used to calculate final emission factor
Avg.	(D)	0.45	(0.91)	

[a]Reference 3.

[b]Reference 5.

[c]Reference 12.

[d]Reference 33.

TABLE 12. PARTICULATE EMISSION FACTOR: INDUCTION FURNACE--WITH BAGHOUSE

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
5	D	0.10	(0.20[a])	Avg. of tests on 2 furnaces
Avg.	(E)	0.10	(0.20)	

[a]Reference 5.

TABLE 13. PARTICULATE EMISSION FACTOR: REVERBERATORY FURNACE--UNCONTROLLED

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
3	B	1.05	(2.1[a])	
5	D	0.75	(1.5[b])	Avg. of 2 furnaces Not used to calculate final emission factor
Avg.	(D)	1.05	(2.1)	

[a]Reference 3.

[b]Reference 5.

TABLE 14. PARTICULATE EMISSION FACTOR: REVERBERATORY FURNACE--WITH BAGHOUSE

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
5	D	0.10	(0.2[a])	Average of 2 furnaces
Avg.	(E)	0.10	(0.2)	

[a]Reference 5.

TABLE 15. PARTICULATE EMISSION FACTOR: POURING AND COOLING--UNCONTROLLED

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
3	B	4.15	(8.3[a])	
5	D	1.38	(2.77[b])	Not used to calculate final emission factor
34	A	0.06	(0.12[c])	Average of 3 runs, each of which is a composite of 3 distinct runs during specific operations. Particle size data also available
Avg.	(D)	2.10	(4.21)	

[a]Reference 3.

[b]Reference 5.

[c]Reference 34.

TABLE 16. PARTICULATE EMISSION FACTOR: MAGNESIUM INOCULATION--UNCONTROLLED

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
3	D	1.25	(2.5[a])	
5	D	0.56	(1.12[b])	
Avg.	(E)	0.90	(1.81)	

[a]Reference 3.

[b]Reference 5.

TABLE 17. PARTICULATE EMISSION FACTOR: SHAKEOUT--UNCONTROLLED

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
3	B	1.57	(3.15[a])	
5	D	0.64	(1.28[b])	Not used to calculate final emission factor
35	C	0.95	(1.90[c])	Not used to calculate final emission factor
Avg.	(D)	1.57	(3.15)	

[a]Reference 3.

[b]Reference 5.

[c]Reference 35.

TABLE 18. PARTICULATE EMISSION FACTOR: SAND HANDLING SYSTEM--UNCONTROLLED

Source No.	Rating	kg/Mg metal	(lb/ton metal)	Comments
3	D	2.21	(4.43[a])	
5	D	1.36	(2.72[b])	
Avg.	(E)	1.79	(3.58)	

[a]Reference 3.

[b]Reference 5.

TABLE 19. PARTICULATE EMISSION FACTOR: SAND HANDLING SYSTEM--WITH SCRUBBER

Source No.	Rating	kg/Mg sand	(lb/ton sand)	Comments
12N	B	B	(0.061[a])	
36	C	0.00060	(0.0012[b])	Average of 3 runs. Not used to calculate final emission factor.
37	B	0.015	(0.030[c])	
Avg.	(D)	0.023	(0.046)	

[a]Reference 12.

[b]Reference 36.

[c]Reference 37.

TABLE 20. PARTICULATE EMISSION FACTOR: SAND HANDLING SYSTEM--WITH VENTURI SCRUBBER

Source No.	Rating	kg/Mg sand	(lb/ton sand)	Comments
12-O	B	0.0055	(0.011[a])	
12P	B	0.020	(0.041[a])	
Avg.	(D)	0.013	(0.026)	

[a]Reference 12.

TABLE 21. PARTICULATE EMISSION FACTOR: SAND HANDLING SYSTEM--WITH BAGHOUSE

Source No.	Rating	kg/Mg sand	(lb/ton sand)	Comments
12Q	B	0.10	(0.20[a])	
Avg.	(D)	0.10	(0.20)	

[a]Reference 12.

Uncontrolled Cupola Emissions

Four sources were used for the determination of the cupola uncontrolled emission factor. These four sources contained all B ranked data. Two sources were not included in the emission factor although their description and data were presented in other portions of this report. These were D rated data. These emissions were close in magnitude to the emission factor. The emission factor was rated C.

Baghouse Controlled Cupola

Four sources were used for the determination of the baghouse controlled cupola emission factor. These four sources were individually rated B and, accordingly, the emission factor was rated C. Three other sources were not included in the emission factor although their description and data were presented in other portions of this report. These were C and D rated data.

Electrostatic Precipitator Controlled Cupola

Two sources were used for the determination of an electrostatic precipitator controlled cupola emission factor. These sources were individually rated D. These two sources were the only data that were available and, accordingly, the emission factor was rated E.

Scrubber Controlled Cupola

Seven sources were used for the determination of the cupola scrubber emission factor. This emission factor included test data from all scrubbers except those with a variable size or venturi throat. The eight sources that were available were all B rated. Four C rated sources were not included in the emission factor calculation, although their description was included in other sections of this report. The emission factor was rated C.

Venturi Scrubber Controlled Cupola

Nine sources were used for the determination of the venturi scrubber controlled cupola emission factor. These sources were individually rated B. This emission factor included all cupolas that were controlled by a venturi or a variable size throat scrubber. Four C rated sources were not included in the final emission factor calculation. The emission factor was rated C.

Uncontrolled Electric Arc Furnaces

Four sources were used to develop the uncontrolled electric arc furnace emission factor. These four sources were individually rated B. One source that was C rated was not used in the final emission factor calculation although its magnitude was close to the average emission factor. The emission factor was rated C.

Baghouse Controlled Electric Arc Furnaces

Seven sources were used to develop the baghouse controlled electric arc furnace emission factor. These seven sources were comprised of six B rated sources and one A rated source. One D rated source was not used. The emission factor was rated C.

Uncontrolled Induction Furnaces

Two sources were used to develop the uncontrolled induction furnace emission factor. These sources were individually rated B. Two other sources, one rated C and one rated D, were not used. The emission factor was rated D due to the limited amount of data that was available.

Baghouse Controlled Induction Furnace

One source was used to develop the emission factor. This source was a D rated source and accordingly the emission factor was rated E.

Uncontrolled Reverberatory Furnace

One source was used to develop the uncontrolled reverberatory furnace emission factor. This source was B rated and accordingly the emission factor was rated D. A D rated source was not included in the development of the emission factor.

Baghouse Controlled Reverberatory Furnace

One source was used to develop the emission factor. This source was D rated and therefore the emission factor was rated E.

Uncontrolled Pouring and Cooling Emissions

Two sources were used to develop the emission factor. These sources were A and B rated. One D rated source was not used in the final emission factor calculation. The emission factor was rated D.

Uncontrolled Magnesium Inoculation

Two sources were used to develop the emission factor for uncontrolled magnesium inoculation. These sources were individually rated C, and accordingly the emission factor was rated E.

Uncontrolled Shakeout

One source was used to develop the uncontrolled shakeout emission factor. This was a B rated source. Three sources were excluded from the final emission factor calculation. These three were comprised of two C rated and one D rated sources. The emission factor was rated D.

Uncontrolled Sand Handling System

Two sources were used to develop the uncontrolled sand handling emission factor. Each source was rated D. The sand handling system classification includes dry sand handling, prepared sand handling, screening, mulling, and drying and reclamation. The emission factor was rated E.

Scrubber Controlled Sand Handling System

Two sources were used to develop the emission factor. These sources were individually rated B. One C rated source was not used. The emission factor was given a D rating.

Venturi Scrubber Controlled Sand Handling System

Two sources were used to develop the emission factor. These two sources were individually rated B. The emission factor was rated D.

Baghouse Controlled Sand Handling System

One source was used to develop the emission factor. This source was rated B. The emission factor was accordingly rated D.

PARTICLE SIZING EMISSION FACTOR CALCULATION

Uncontrolled Cupola

The uncontrolled cupola emission factor for particle sizing data was calculated from two sources of data. All sources were rated B. The emission factor was accordingly rated C.

Baghouse Controlled Cupola

One source of data was used to develop the particle size emission factor for baghouse controlled cupola emissions. This source was rated C and accordingly the emission factor was rated E.

Venturi Scrubber Controlled Cupola

Three sources of data were used to develop the emission particle size factor for venturi scrubber controlled cupolas. These three sources were all rated B and the emission factor was accordingly rated C.

Pouring Processes

The particle size emission factor for uncontrolled pouring emissions was developed from one source. This source was rated A. There was one C rated source that was not used to develop this emission factor. This emission factor was therefore rated D.

Cooling Processes

The particle size emission factor for uncontrolled cooling emissions was developed from one source. This source was rated A. The emission factor was therefore rated D.

Sand System - Shakeout

The particle size emission factor for uncontrolled shakeout emissions was developed from one source. This source was rated C. The emission factor was rated E.

SECTION 4

PROPOSED AP-42 SECTION

7.10 GRAY IRON FOUNDRIES

7.10.1 General[1-5]

Gray iron foundries produce gray iron castings from scrap iron, pig iron and foundry returns by melting, alloying and molding. The production of gray iron castings involves a number of integrated steps, which are outlined in Figures 7.10-1 and 7.10-2. The four major production steps are raw materials handling and preparation, metal melting, mold and core production, and casting and finishing.

Raw Materials Handling And Preparation - Handling operations include receiving, unloading, storing and conveying of all raw materials for both furnace charging and mold and core preparation. The major groups of raw materials required for furnace charging are metallics, fluxes and fuels. Metallic raw materials include pig iron, iron and steel scrap, foundry returns and metal turnings. Fluxes include carbonates (limestone, dolomite), fluoride (fluorspar), and carbide compounds (calcium carbide).[4] Fuels include coal, oil, natural gas and coke. Coal, oil and natural gas are used to fire reverberatory furnaces. Coke, a derivative of coal, is used as a fuel in cupola furnaces. Carbon electrodes are required for electric arc furnaces.

As shown in Figures 7.10-1 and 7.10-2, the raw materials, metallics and fluxes are added to the melting furnaces directly. For electric induction furnaces, however, the scrap metal added to the furnace charge must first be pretreated to remove any grease and/or oil, which can cause explosions. Scrap metals may be degreased with solvents, by centrifugation, or by preheating to combust the organics.

In addition to the raw materials used to produce the molten metal, a variety of materials is needed to prepare the sand cores and molds that form the iron castings. Virgin sand, recycled sand and chemical additives are combined in a sand handling system typically comprising receiving areas, conveyors, storage silos and bins, mixers (sand mullers), core and mold making machines, shakeout grates, sand cleaners, and sand screening.

Raw materials are received in ships, railroad cars, trucks and containers, then transferred by truck, loaders and conveyors to both open piles and enclosed storage areas. When needed, the raw materials are transferred from storage to process areas by similar means.

Metal Melting - The furnace charge includes metallics, fluxes and fuels. The composition of the charge depends upon the specific metal characteristics required. Table 7.10-1 lists the different chemical compositions of typical irons produced. The three most common furnaces used in the gray iron foundry industry are cupolas, electric arc, and electric induction furnaces.

The cupola, which is the major type of furnace used in industry today, is typically a vertical cylindrical steel shell with either a refractory lined or water cooled inner wall. Refractory linings usually consist of silica brick, or dolomite or magnesium brick. Water cooled linings, which involve circulating

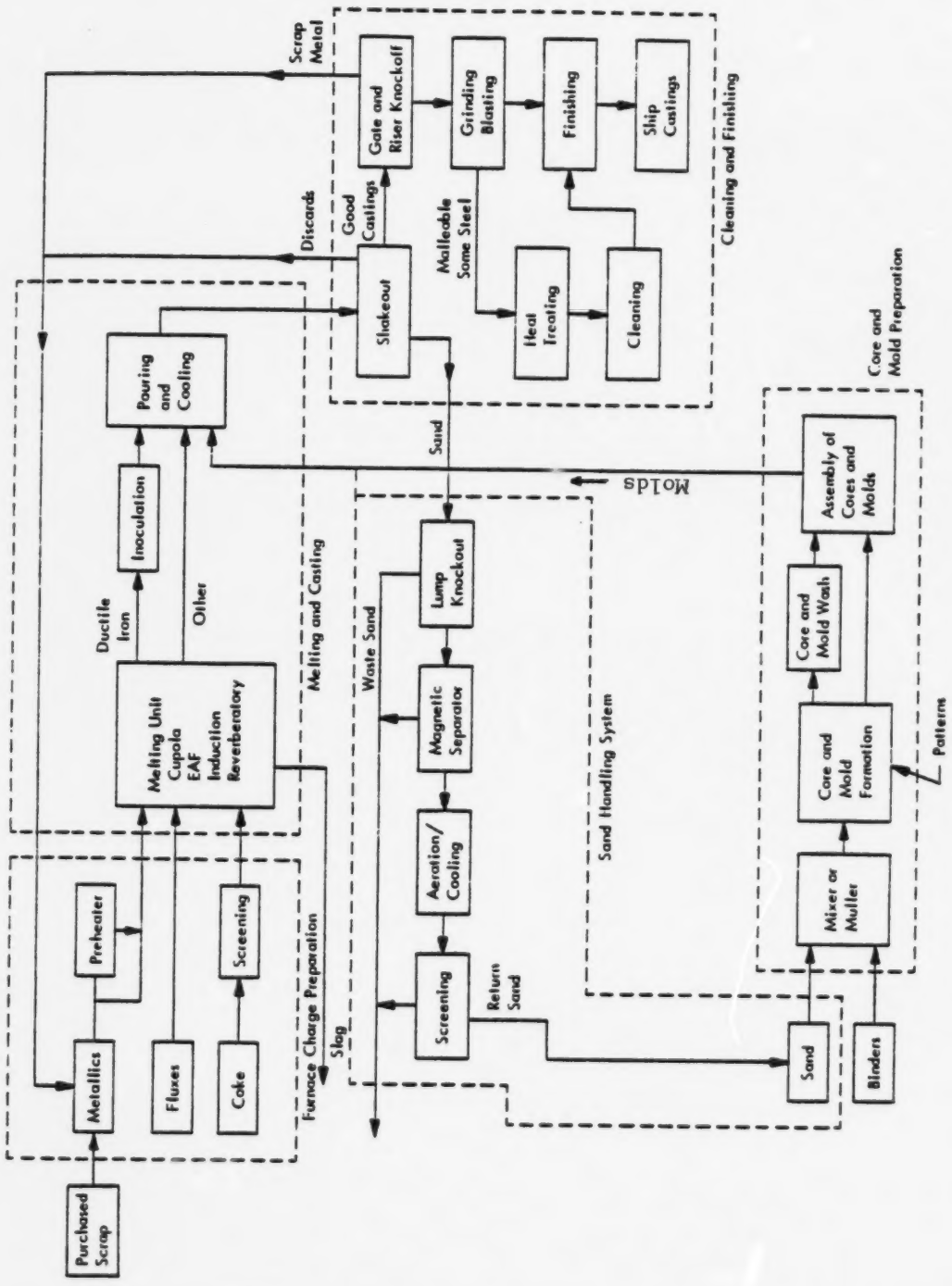

Figure 7.10-1. Typical iron foundry diagram.[1]

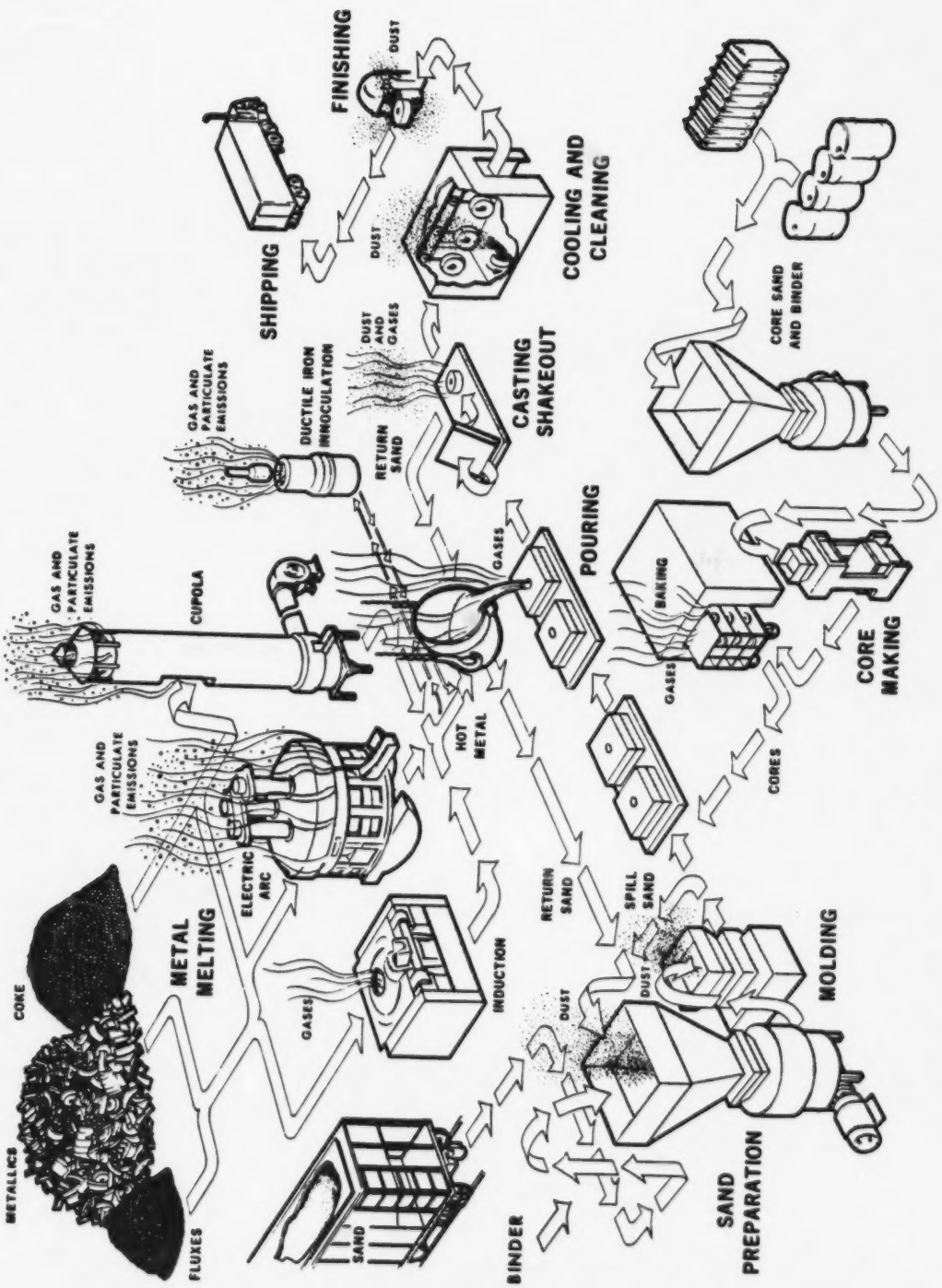

Figure 7.10-2. Emission points in a typical iron foundry.[2-3]

TABLE 7.10-1. CHEMICAL COMPOSITION OF FERROUS CASTINGS BY PERCENTAGE

Element	Gray iron	Malleable iron (as white iron)	Ductile iron[a]	Steel
Carbon	2.5 - 4.0	1.8 - 3.6	3.0 - 4.0	<2.0[b]
Silicon	1.0 - 3.0	0.5 - 1.9	1.4 - 2.0	0.2 - 0.8
Manganese	0.40 - 1.0	0.25 - 0.80	0.5 - 0.8	0.5 - 1.0
Sulfur	0.05 - 0.25	0.06 - 0.20	<0.12	<0.06
Phosphorus	0.05 - 1.0	0.06 - 0.18	<0.15	<0.05

[a]Necessary chemistry also includes 0.01 - 1.0% Mg.
[b]Steels are further classified by carbon content: low carbon, <0.20%; medium carbon, 0.20 - 0.50%; high carbon, >0.50%.

water around the outer steel shell, are used to protect the furnace wall from interior temperatures. The cupola is charged at the top with alternate layers of coke, metallics and fluxes.[2] The cupola is the only furnace type to use coke as a fuel; combustion air used to burn the coke is introduced through tuyeres located at the base of the cupola.[2] Cupolas use either cold blast air, air introduced at ambient temperature, or hot blast air with a regenerative system which utilizes heat from the cupola exhaust gases to preheat the combustion air.[2] Iron is melted by the burning coke and flows down the cupola. As the melt proceeds, new charges are added at the top. The flux removes nonmetallic impurities in the iron to form slag. Both the molten iron and the slag are removed through tap holes at the bottom of the cupola. Periodically, the heat period is completed, and the bottom of the cupola is opened to remove the remaining unburned material. Cupola capacities range from 1.0 to 27 megagrams per hour (1 to 30 tons per hour), with a few larger units approaching 90 megagrams per hour (100 tons per hour). Larger furnaces operate continuously and are inspected and cleaned at the end of each week or melting cycle.

Electric arc furnaces (EAF) are large, welded steel cylindrical vessels equipped with a removable roof through which three retractable carbon electrodes are inserted. The electrodes are lowered through the roof of the furnace and are energized by three phase alternating current, creating arcs that melt the metallic charge with their heat. Additional heat is produced by the resistance of the metal between the arc paths. The most common method of charging an electric arc furnace is by removing the roof and introducing the raw materials directly. Alternative methods include introducing the charge through a chute cut in the roof or through a side charging door in the furnace shell . Once the melting cycle is complete, the carbon electrodes are raised, and the roof is removed. The vessel is tilted, and the molten iron is poured into a ladle. Electric arc furnace capacities range from 0.23 to 59 megagrams (0.25 to 65 tons). Nine to 11 pounds of electrode are consumed per ton of metal melted.

Electric induction furnaces are either cylindrical or cup shaped refractory lined vessels that are surrounded by electrical coils which, when energized with high frequency alternating current, produce a fluctuating electromagnetic field to heat the metal charge. For safety reasons, the scrap metal added to the furnace charge is cleaned and heated before being introduced into the furnace. Any oil or moisture on the scrap could cause an explosion in the furnace. Induction furnaces are kept closed except when charging, skimming and tapping. The molten metal is tapped by tilting and pouring through a hole in the side of the vessel. Induction furnaces also may be used for metal refining in conjunction with melting in other furnaces and for holding and superheating the molten metal before pouring (casting).

The basic melting process operations are 1) furnace charging, in which metal, scrap, alloys, carbon, and flux are added to the furnace; 2) melting, during which the furnace remains closed; 3) backcharging, which involves the addition of more metal and alloys, as needed; 4) refining and treating, during which the chemical composition is adjusted to meet product specifications; 5) slag removing; and 6) tapping molten metal into a ladle or directly into molds.

Mold And Core Production - Molds are forms used to shape the exterior of castings. Cores are molded sand shapes used to make the internal voids in castings. Cores are made by mixing sand with organic binders, molding the sand into a core, and baking the core in an oven. Molds are prepared of a mixture of wet sand, clay and organic additives to make the mold shapes, which are usually dried with hot air. Cold setting binders are being used more frequently in both core and mold production. The green sand mold, the most common type, uses moist sand mixed with 4 to 6 percent clay (bentonite) for bonding. The mixture is 4 to 5 percent water content. Added to the mixture, to prevent casting defects from sand expansion when the hot metal is poured, is about 5 percent organic material, such as sea coal (a pulverized high volatility bituminous coal), wood flour, oat hulls, pitch or similar organic matter.

Common types of gray iron cores are:

- Oil core, with typical sand binder percents of 1.0 core oil, 1.0 cereal, and 0 to 1 pitch or resin. Cured by oven baking at 205 to 315°C (400 to 600°F), for 1 to 2 hours.

- Shell core, with sand binder typically 3 to 5 percent phenolic and/or urea formaldehyde, with hexamine activator. Cured as a thin layer on a heated metal pattern at 205 to 315°C (400 to 600°F), for 1 to 3 minutes.

- Hot box core, with sand binder typically 3 to 5 percent furan resin, with phosphoric acid activator. Cured as a solid core in a heated metal pattern at 205 to 315°C (400 to 600°F), for 0.5 to 1.5 minutes.

- Cold set core, with typical sand binder percents of 3 to 5 furan resin, with phosphoric acid activator; or 1 to 2 core oil, with phosphoric acid activator. Hardens in the core box. Cured for 0.5 to 3 hours.

- Cold box core, with sand binder typically 1 to 3 percent of each of two resins, activated by a nitrogen diluted gas. Hardens when the green core is gassed in the box with polyisocyanate in air. Cured for 10 to 30 seconds.

Used sand from castings shakeout is recycled to the sand preparation area and cleaned to remove any clay or carbonaceous buildup. The sand is then screened and reused to make new molds. Because of process losses and discard of a certain amount of sand because of contamination, makeup sand is added.

Casting And Finishing - After the melting process, molten metal is tapped from the furnace. Molten iron produced in cupolas is tapped from the bottom of the furnace into a trough, thence into a ladle. Iron produced in electric arc and induction furnaces is poured directly into a ladle by tilting the furnace. At this point, the molten iron may be treated with magnesium to produce ductile iron. The magnesium reacts with the molten iron to nodularize the carbon in the molten metal, giving the iron less brittleness. At times, the molten metal may be inoculated with graphite to adjust carbon content. The treated molten iron is then ladled into molds and transported to a cooling area, where it solidifies in the mold and is allowed to cool further before separation (shakeout) from the mold and core sand. In larger, more mechanized foundries, the molds are conveyed automatically through a cooling tunnel. In simpler foundries, molds are placed on an open floor space, and the molten iron is poured into the molds and allowed to cool partially. Then the molds are placed on a vibrating grid to shake the mold and core sand loose from the casting. In the simpler foundries, molds, core sand and castings are separated manually, and the sand from the mold and core is then returned to the sand handling area.

When castings have cooled, any unwanted appendages, such as spurs, gates, and risers, are removed. These appendages are removed with oxygen torch, abrasive band saw, or friction cutting tools. Hand hammers may be used, in less mechanized foundries. to knock the appendages off. After this, the castings are subjected to abrasive blast cleaning and/or tumbling to remove any remaining mold sand or scale.

Another step in the metal melting process involves removing the slag in the furnace through a tapping hole or door. Since the slag is lighter than molten iron, it remains atop the molten iron and can be raked or poured out of cupola furnaces through the slag hole located above the level of the molten iron. Electric arc and induction furnaces are tilted backwards, and their slag is removed through a slag door.

7.10.2 Emissions And Controls

Emissions from the raw materials handling operations are fugitive particulate generated from the receiving, unloading, storage and conveying of raw materials. These emissions are controlled by enclosing the major emission points (e. g., conveyor belt transfer points) and routing air from the enclosures through fabric filters or wet collectors. Figure 7.10-2 shows emission points and types of emissions from a typical foundry.

Scrap preparation with heat will emit smoke, organic compounds and carbon monoxide, and scrap preparation with solvent degreasers will emit organics. Catalytic incinerators and afterburners can control about 95 percent of organic and carbon monoxide emissions. (See Section 4.6, Solvent Degreasing.)

Emissions released from the melting furnaces include particulate matter, carbon monoxide, organic compounds, sulfur dioxide, nitrogen oxides and small quantities of chloride and fluoride compounds. The particulates, chlorides and

fluorides are generated from incomplete combustion of coke, carbon additives, flux additions, and dirt and scale on the scrap charge. Organic material on the scrap, the consumption of coke in the furnace, and the furnace temperature all affect the amount of carbon monoxide generated. Sulfur dioxide emissions, characteristic of cupola furnaces, are attributable to sulfur in the coke. Fine particulate fumes emitted from the melting furnaces come from the condensation of volatilized metal and metal oxides.

During melting in an electric arc furnace, particulate emissions are generated by the vaporization of iron and the transformation of mineral additives. These emissions occur as metallic and mineral oxides. Carbon monoxide emissions come from the combustion of the graphite lost from the electrodes and the carbon added to the charge. Hydrocarbons may come from vaporization and partial combustion of any oil remaining on the scrap iron added to the furnace charge.

The highest concentrations of furnace emissions occur during charging, backcharging, alloying, slag removal, and tapping operations, because furnace lids and doors are opened. Generally, these emissions escape into the furnace building or are collected and vented through roof openings. Emission controls for melting and refining operations usually involve venting the furnace gases and fumes directly to a control device. Controls for fugitive furnace emissions include canopy hoods or special hoods near the furnace doors and tapping hoods to capture emissions and route them to emission control systems.

High energy scrubbers and baghouses (fabric filters) are used to control particulate emissions from cupolas and electric arc furnaces in this country. When properly designed and maintained, these control devices can achieve respective efficiencies of 95 and 98 percent. A cupola with such controls typically has an afterburner with up to 95 percent efficiency, located in the furnace stack, to oxidize carbon monoxide and to burn organic fumes, tars and oils. Reducing these contaminants protects the particulate control device from possible plugging and explosion. Because induction furnaces emit negligible amounts of hydrocarbon and carbon monoxide emissions, and relatively little particulate, they are usually uncontrolled.[2]

The major pollutant emitted in mold and core production operations is particulate from sand reclaiming, sand preparation, sand mixing with binders and additives, and mold and core forming. Organics, carbon monoxide and particulate are emitted from core baking, and organic emissions from mold drying. Baghouses and high energy scrubbers generally are used to control particulate from mold and core production. Afterburners and catalytic incinerators can be used to control organics and carbon monoxide emissions.

Particulate emissions are generated during the treatment and inoculation of molten iron before pouring. For example, during the addition of magnesium to molten metal to produce ductile iron, the reaction between the magnesium and molten iron is very violent, accompanied by emissions of magnesium oxides and metallic fumes. Emissions from pouring consist of hot metal fumes, and carbon monoxide, organic compounds and particulate evolved from the mold and core materials contacting the molten iron. Emissions from pouring normally are captured by a collection system and vented, either controlled or uncontrolled, to the atmosphere. Emissions continue as the molds cool. A significant quantity of particulate is also generated during the casting shakeout operation. These fugitive emissions must be captured, and they usually are controlled by

either high energy scrubbers or bag filters.

Finishing operations emit large, coarse particles during the removal of burrs, risers and gates, and during shot blast cleaning. These emissions are easily controlled by cyclones and baghouses.

Emission factors for total particulate from gray iron furnaces are presented in Table 7.10-2, and emission factors for gaseous and lead pollutants are given in Table 7.10-3. Tables 7.10-4 and 7.10-5, respectively, give factors for ancillary process operations and fugitive sources and for specific particle sizes. Particle size factors and distributions are presented also in Figures 7.10-3 through 7.10-8.

TABLE 7.10-2. EMISSION FACTORS FOR GRAY IRON FURNACES[a]

Process	Control device	Total particulate		Emission Factor Rating
		kg/Mg	lb/ton	
Cupola	Uncontrolled[b]	6.9	13.8	C
	Scrubber[c]	1.6	3.1	C
	Venturi scrubber[d]	1.5	3.0	C
	Electrostatic precipitator[e]	0.7	1.4	E
	Baghouse[f]	0.3	0.7	C
	Single wet cap[g]	4.0	8.0	B
	Impingement scrubber[g]	2.5	5.0	B
	High energy scrubber[g]	0.4	0.8	B
Electric arc furnace	Uncontrolled[h]	6.3	12.7	C
	Baghouse[j]	0.2	0.4	C
Electric induction furnace	Uncontrolled[k]	0.5	0.9	D
	Baghouse[m]	0.1	0.2	E
Reverberatory	Uncontrolled[n]	1.1	2.1	D
	Baghouse[m]	0.1	0.2	E

[a]Expressed as weight of pollutant/weight of gray iron produced.
[b]References 1,7,9-10.
[c]References 12,15. Includes averages for wet cap and other scrubber types not already listed.
[d]References 12,17,19.
[e]References 8,11.
[f]References 12-14.
[g]References 8,11,29-30.
[h]References 1,6,23.
[j]References 6,23-24.
[k]References 1,12. For metal melting only.
[m]Reference 4.
[n]Reference 1.

TABLE 7.10-3. GASEOUS AND LEAD EMISSION FACTORS FOR GRAY IRON FOUNDRIES[a]

EMISSION FACTOR RATING: B

Furnace type	Carbon monoxide		Sulfur dioxide		Nitrogen oxides		Volatile organic compounds		Lead[b]	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Cupola										
Uncontrolled	73[c]	145[c]	0.6S[d]	1.2S[d]	-	-	-	-	0.05-0.6	0.1-1.1
High energy scrubber	-	-	0.3S[d]	0.6S[d]	-	-	-	-	-	-
Electric arc[e]	0.5-19	1-37	Neg	Neg	0.02-0.3	0.04-0.6	0.03-0.15	0.06-0.3	-	-
Electric induction[f]	Neg	Neg	Neg	Neg	-	-	-	-	0.005-0.05	0.009-0.1
Reverberatory	-	-	-	-	-	-	-	-	0.006-0.07	0.012-0.14

[a]Expressed as weight of pollutant/weight of gray iron produced. Dash = no data. Neg = negligible.
[b]References 11,31,34.
[c]Reference 2.
[d]Reference 4. S = % sulfur in the coke. Assumes 30% of sulfur is converted to SO_2.
[e]Reference 4,6.
[f]References 8,11,29-30.

TABLE 7.10-4. PARTICULATE EMISSION FACTORS FOR ANCILLARY PROCESS OPERATIONS AND FUGITIVE SOURCES AT GRAY IRON FOUNDRIES [a]

Process	Control device	Total emission factor		Emitted to work environment		Emitted to atmosphere		Emission Factor Rating
		kg/Mg metal	lb/ton metal	kg/Mg metal	lb/ton metal	kg/Mg metal	lb/ton metal	
Scrap and charge handling, heating[b]	Uncontrolled	0.3	0.6	0.25	0.5	0.1	0.2	D
Magnesium treatment[c]	Uncontrolled	0.9	1.8	0.9	1.8	0.2	0.4	E
Inoculation[d]	Uncontrolled	1.5 - 2.5	3 - 5	-	-	-	-	D
Pouring, cooling[e]	Uncontrolled	2.1	4.2					D
Shakeout[f]	Uncontrolled[c]	1.6	3.2					D
Cleaning, finishing[b]	Uncontrolled	8.5	17	0.15	0.3	0.05	0.1	D
Sand handling[g]	Uncontrolled[c]	1.8	3.6	-	-	-	-	E
	Scrubber[h]	0.023	0.046	-	-	-	-	D
	Baghouse[j]	0.10	0.20	-	-	-	-	D
Core making, baking[b]	Uncontrolled	0.6	1.1	0.6	1.1	0.6	1.1	D

[a] Expressed as weight of pollutant/weight of gray iron produced, except as noted. Dash = no data.
[b] Reference 4.
[c] References 1,4.
[d] Reference 35.
[e] References 1,3,25.
[f] Reference 1.
[g] Kg of sand/Mg of sand handled.
[h] References 12,27.
[j] Reference 12.

TABLE 7.10-5. PARTICLE SIZE DISTRIBUTION DATA AND EMISSION FACTORS FOR GRAY IRON FOUNDRIES[a]

Source	Emission Factor Rating	Particle size (um)	Cumulative mass % ≤ stated size[b]	Cumulative mass emission factor kg/Mg metal	Cumulative mass emission factor lb/ton metal
Cupola Furnace[b] Uncontrolled	C	0.5	44.3	3.1	6.1
		1.0	69.1	4.8	9.5
		2.0	79.6	5.5	11.0
		2.5	84.0	5.8	11.6
		5.0	90.1	6.2	12.4
		10.0	90.1	6.2	12.4
		15.0	90.6	6.3	12.5
			100.0	6.9	13.8
Controlled by baghouse	E	0.5	83.4	0.33	0.58
		1.0	91.5	0.37	0.64
		2.0	94.2	0.38	0.66
		2.5	94.9	0.38	0.66
		5.0	94.9	0.38	0.66
		10.0	94.9	0.38	0.66
		15.0	95.0	0.38	0.67
			100.0	0.4	0.7
Controlled by venturi scrubber[c]	C	0.5	56.0	0.84	1.7
		1.0	70.2	1.05	2.1
		2.0	77.4	1.16	2.3
		2.5	77.7	1.17	2.3
		5.0	77.7	1.17	2.3
		10.0	77.7	1.17	2.3
		15.0	77.7	1.17	2.3
			100.0	1.5	3.0

TABLE 7.10-5 (cont.).

Process	Particle size (um)	Cumulative mass % ≤ stated size[b]	Cumulative mass emission factor kg/Mg metal	Cumulative mass emission factor lb/ton metal	Emission Factor Rating
Electric arc furnace[d]					
Uncontrolled	1.0	13.0	0.8	1.6	E
	2.0	57.5	3.7	7.3	
	5.0	82.0	5.2	10.4	
	10.0	90.0	5.8	11.4	
	15.0	93.5	6.0	11.9	
		100.0	6.4	12.7	
Pouring, cooling[b]					
Uncontrolled	0.5	d	-	-	D
	1.0	19.0	0.40	0.80	
	2.0	20.0	0.42	0.84	
	2.5	24.0	0.50	1.00	
	5.0	34.0	0.71	1.43	
	10.0	49.0	1.03	2.06	
	15.0	72.0	1.51	3.02	
		100.0	2.1	4.2	
Shakeout[b]					
Uncontrolled	0.5	23.0	0.37	0.74	E
	1.0	37.0	0.59	1.18	
	2.0	41.0	0.66	1.31	
	2.5	42.0	0.67	1.34	
	5.0	44.0	0.70	1.41	
	10.0	70.0	1.12	2.24	
	15.0	99.9	1.60	3.20	
		100.0	1.60	3.20	

[a]Expressed as weight of pollutant/weight of metal melted (produced). Dash = no data. Mass emission rate data available in Tables 7.10-2 and 7.10-4 to calculate size specific emission factors.
[b]References 13,21-22,25-26. See Figures 7.10-3 through 7.10-8.
[c]Pressure drop across venturi: approx. 102 inches of water.
[d]Reference 3, Exhibit VI-15. Averaged from data on two foundries. Because original test data could not be obtained, Emission Factor Rating is E.

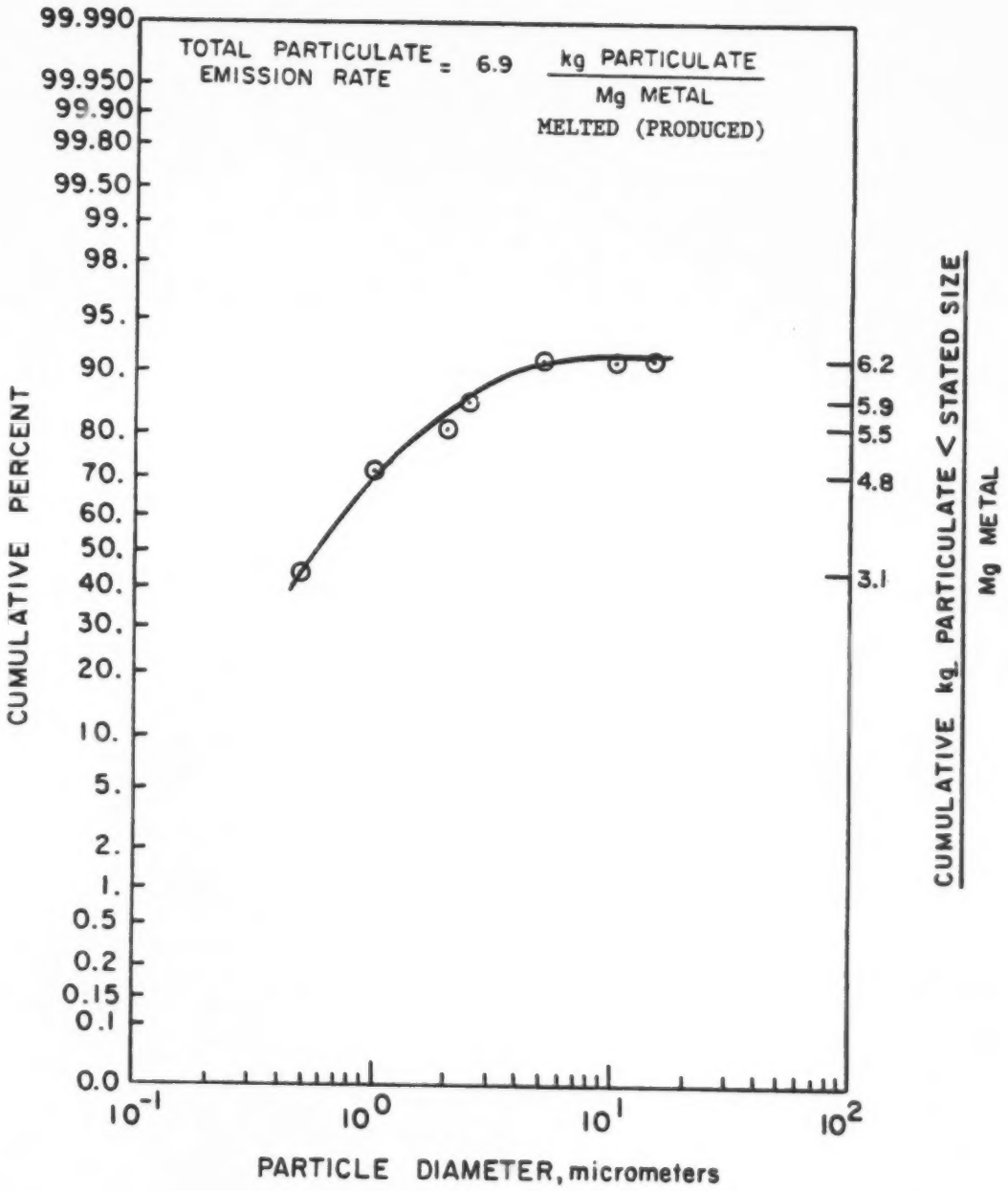

Figure 7.10-3. Particle size distribution for uncontrolled cupola.[21-22]

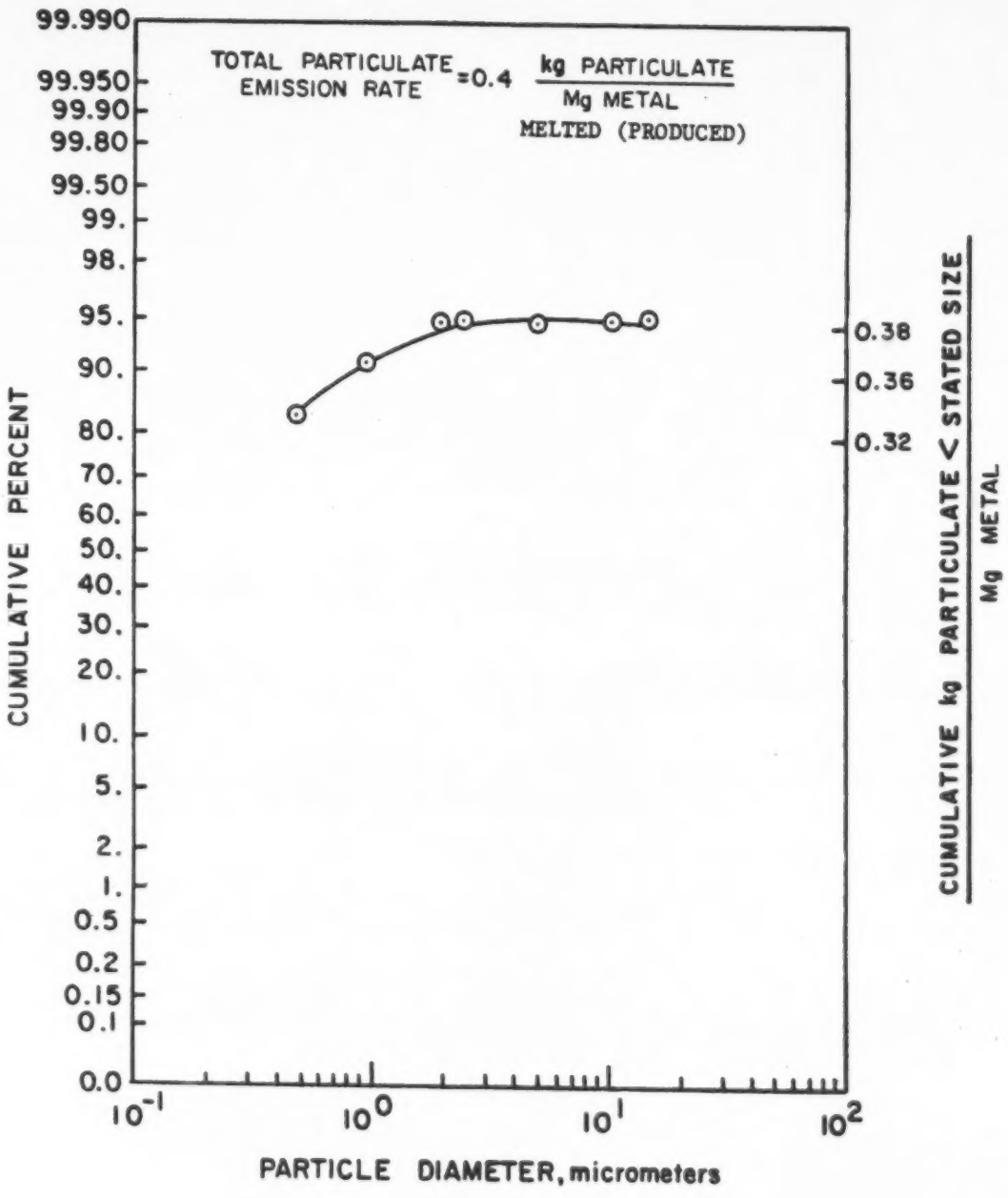

Figure 7.10-4. Particle size distribution for baghouse controlled cupola.[13]

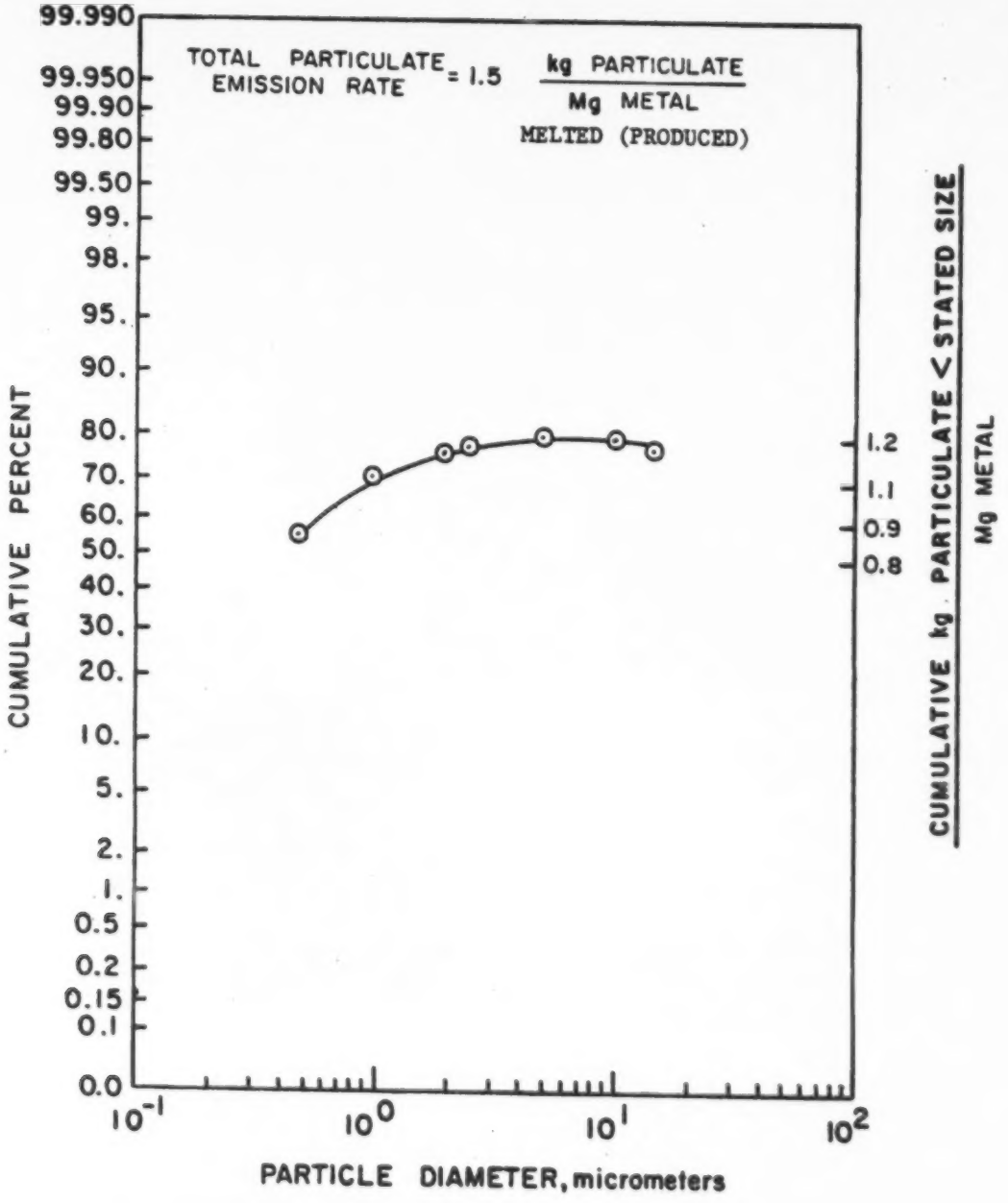

Figure 7.10-5. Particle size distribution for venturi scrubber controlled cupola.[21-22]

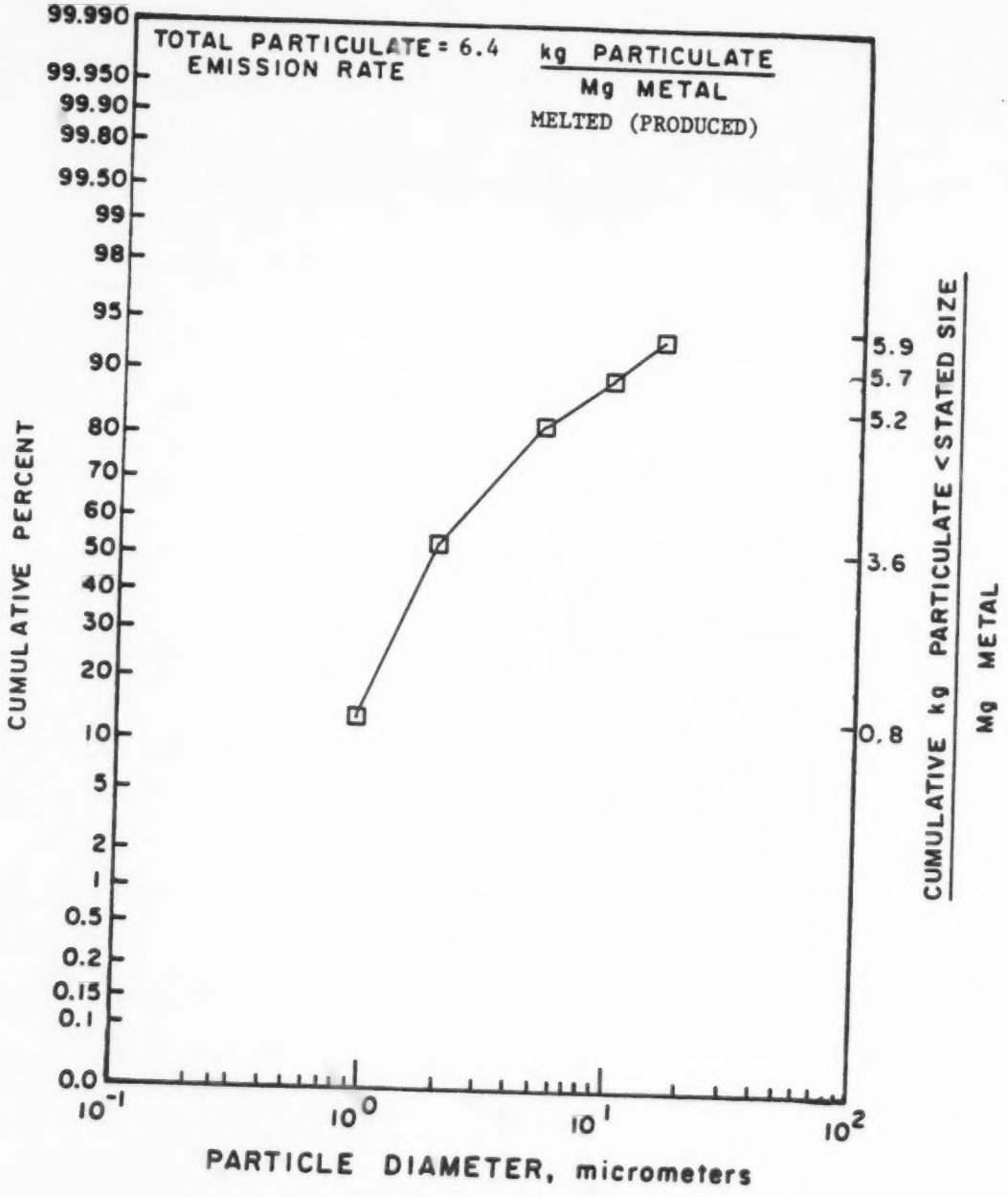

Figure 7.10-6. Particle size distribution for uncontrolled electric arc furnace.[3]

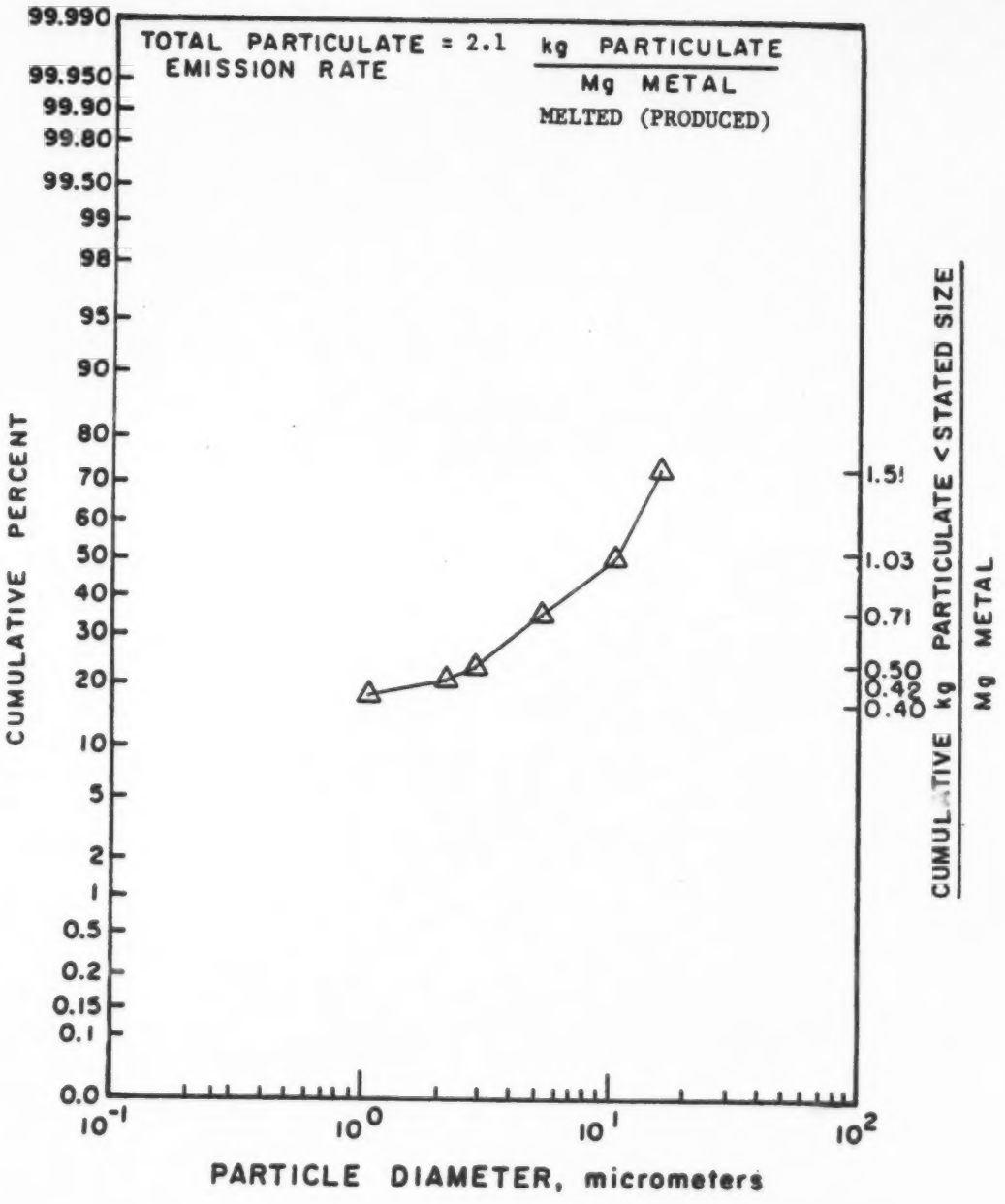

Figure 7.10-7. Particle size distribution for uncontrolled pouring and cooling.[25]

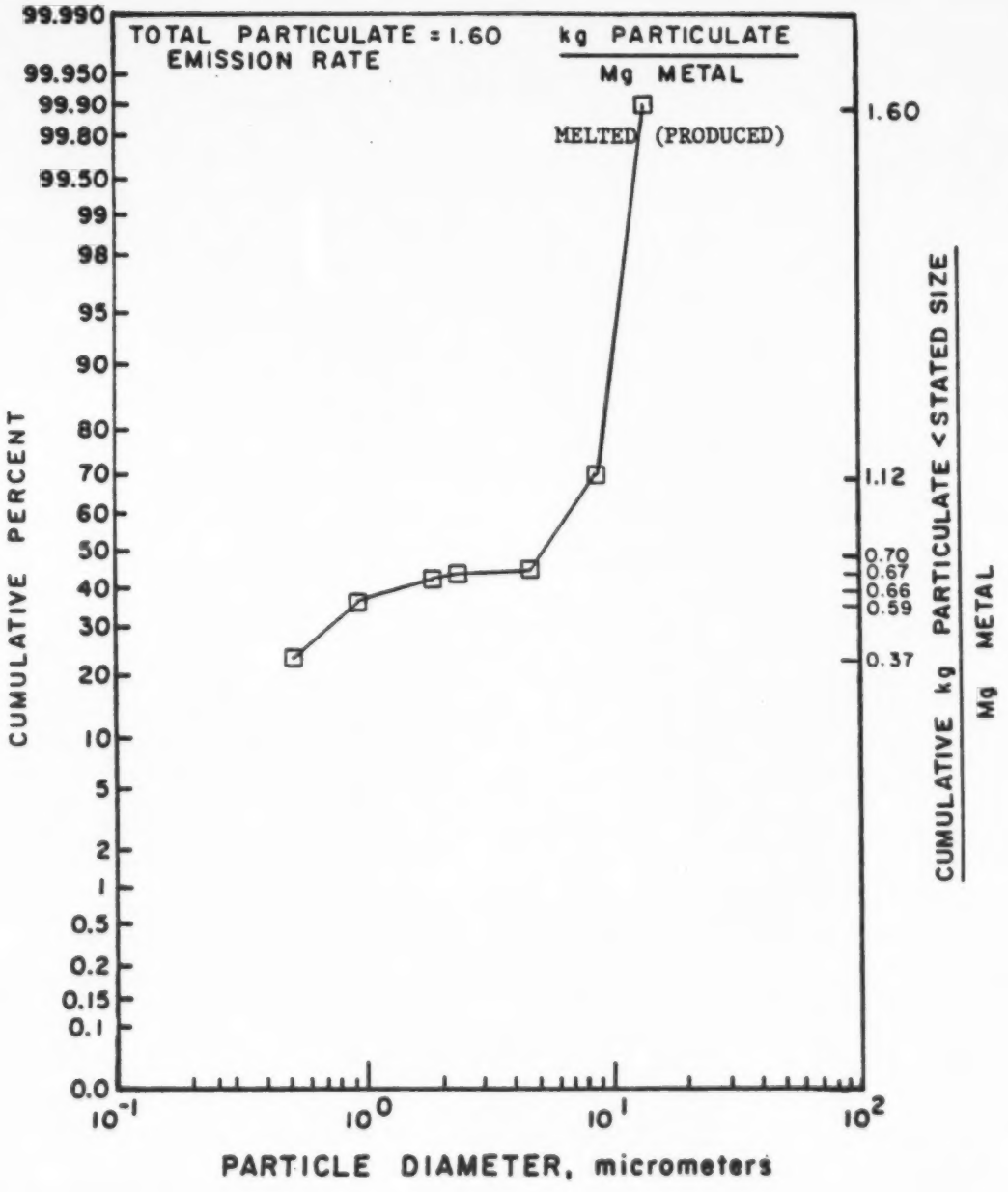

Figure 7.10-8. Particle size distribution for uncontrolled shakeout.[26]

REFERENCES FOR SECTION 7.10

1. Summary of Factors Affecting Compliance by Ferrous Foundries, Volume I: Text, EPA-340/1-80-020, U. S. Environmental Protection Agency, Washington, DC, January 1981.

2. Air Pollution Aspects of the Iron Foundry Industry, APTD-0806, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1971.

3. Systems Analysis of Emissions and Emission Control in the Iron Foundry Industry, Volume II: Exhibits, APTD-0645, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1971.

4. J. A. Davis, et al., Screening Study on Cupolas and Electric Furnaces in Gray Iron Foundries, EPA Contract No. 68-01-0611, Battelle Laboratories, Columbus, OH, August 1975.

5. R. W. Hein, et al., Principles of Metal Casting, McGraw-Hill, New York, 1967.

6. P. Fennelly and P. Spawn, Air Pollution Control Techniques for Electric Arc Furnaces in the Iron and Steel Foundry Industry, EPA-450/2-78-024, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1978.

7. R. D. Chmielewski and S. Calvert, Flux Force/Condensation Scrubbing for Collecting Fine Particulate from Iron Melting Cupola, EPA-600/7-81-148, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1981.

8. W. F. Hammond and S. M. Weiss, "Air Contaminant Emissions From Metallurgical Operations In Los Angeles County", Presented at the Air Pollution Control Institute, Los Angeles, CA, July 1964.

9. Particulate Emission Test Report On A Gray Iron Cupola at Cherryville Foundry Works, Cherryville, NC, Department Of Natural And Economic Resources, Raleigh, NC, December 18, 1975.

10. J. N. Davis, "A Statistical Analysis of the Operating Parameters Which Affect Air Pollution Emissions From Cupolas", November 1977. Further information unavailable.

11. Air Pollution Engineering Manual, Second Edition, AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1973. Out of Print.

12. Written communication from Dean Packard, Department Of Natural Resources, Madison, WI, to Douglas Seeley, Alliance Technology, Bedford, MA, April 15, 1982.

13. Particulate Emissions Testing At Opelika Foundry, Birmingham, AL, Air Pollution Control Commission, Montgomery, AL, November 1977 - January 1978.

14. Written communication from Minnesota Pollution Control Agency, St. Paul, MN, to Mike Jasinski, Alliance Technology, Bedford, MA, July 12, 1982.

15. Stack Test Report, Dunkirk Radiator Corporation Cupola Scrubber, State Department Of Environmental Conservation, Region IX, Albany, NY, November 1975.

16. Particulate Emission Test Report For A Scrubber Stack For A Gray Iron Cupola At Dewey Brothers, Goldsboro, NC, Department Of Natural Resources, Raleigh, NC, April 7, 1978.

17. Stack Test Report, Worthington Corp. Cupola, State Department Of Environmental Conservation, Region IX, Albany, NY, November 4-5, 1976.

18. Stack Test Report, Dresser Clark Cupola Wet Scrubber, Orlean, NY, State Department Of Environmental Conservation, Albany, NY, July 14 & 18, 1977.

19. Stack Test Report, Chevrolet Tonawanda Metal Casting, Plant Cupola #3 And Cupola #4, Tonawanda, NY, State Department Of Environmental Conservation, Albany, NY, August 1977.

20. Stack Analysis For Particulate Emission, Atlantic States Cast Iron Foundry/Scrubber, State Department Of Environmental Protection, Trenton, NJ, September 1980.

21. S. Calvert, et al., Fine Particle Scrubber Performance, EPA-650/2-74-093, U. S. Environmental Protection Agency, Cincinnati, OH, October 1974.

22. S. Calvert, et al., National Dust Collector Model 850 Variable Rod Module Venturi Scrubber Evaluation, EPA-600/2-76-282, U. S. Environmental Protection Agency, Cincinnati, OH, December 1976.

23. Source Test, Electric Arc Furnace At Paxton-Mitchell Foundry, Omaha, NB, Midwest Research Institute, Kansas City, MO, October 1974.

24. Source Test, John Deere Tractor Works, East Moline, IL, Gray Iron Electric Arc Furnace, Walden Research, Wilmington, MA, July 1974

25. S. Gronberg, Characterization Of Inhalable Particulate Matter Emissions From An Iron Foundry, Lynchburg Foundry, Archer Creek Plant, EPA-600/X-85-328, U. S. Environmental Protection Agency, Cincinnati, OH, August 1984.

26. Particulate Emissions Measurements From The Rotoclone And General Casting Shakeout Operations Of United States Pipe & Foundry, Inc, Anniston, AL, State Air Pollution Control Commission, Montgomery, AL. Further information unavailable.

27. Report Of Source Emissions Testing At Newbury Manufacturing, Talladega, AL, State Air Pollution Control Commission, Montgomery, AL, May 15-16, 1979.

28. Particulate Emission Test Report For A Gray Iron Cupola At Hardy And Newson, La Grange, NC, State Department Of Natural Resources And Community Development, Raleigh, NC, August 2-3, 1977.

29. H. R. Crabaugh, et al., "Dust And Fumes From Gray Iron Cupolas: How Are They Controlled In Los Angeles County", Air Repair, 4(3):125-130, November 1954.

30. J. M. Kane, "Equipment For Cupola Control", American Foundryman's Society Transactions, 64:525-531, 1956.

31. Control Techniques For Lead Air Emissions, 2 Volumes, EPA-450/2-77-012, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

32. W. E. Davis, Emissions Study Of Industrial Sources Of Lead Air Pollutants, 1970, APTD-1543, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1973.

33. Emission Test No. EMB-71-CI-27, Office Of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1972.

34. Emission Test No. EMB-71-CI-30, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1972.

35. John Zoller, et al., Assessment Of Fugitive Particulate Emission Factors For Industrial Processes, EPA-450/3-78-107, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1978.

36. J. Jeffery, et al., Inhalable Particulate Source Category Report For The Gray Iron Foundry Industry, TR-83-15-G, EPA Contract No. 68-02-3157, GCA Corporation, Bedford, MA, July 1986.

REFERENCES FOR SECTIONS 1 TO 3

1. Air Pollution Aspects of the Iron Foundry Industry, APTD 0806 (NTIS No. PB204712), U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1971.

2. Systems Analysis of Emissions and Emission Control in the Iron Foundry Industry, Volume II: Exhibits, APTD 0645 (NTIS No. PB198349), U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1971.

3. Summary of Factors Affecting Compliance by Ferrous Foundries, Volume I: Text, EPA-340/1-80-020, U. S. Environmental Protection Agency, Washington, DC, January 1981.

4. Baldwin, V. H., Jr., Environmental Assessment of Iron Casting, EPA-600/2-80-021 (NTIS No. PB 80-187545), U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1980.

5. Davis, J. A., et al., Screening Study on Cupolas and Electric Furnaces in Gray Iron Foundries, EPA Contract No. 68-01-0611, Battelle Laboratories, Columbus, OH, August 1975.

6. Fennelly, P. and P. Spawn, Air Pollution Control Techniques for Electric Arc Furnaces in the Iron and Steel Foundry Industry, EPA-450/2-78-024 (NTIS No. PB283650), U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1978.

7. Chmielewski, R. D. and S. Calvert, Flux Force/Condensation Scrubbing for Collecting Fine Particulate from Iron Melting Cupolas, EPA-600/7-81-148 (NTIS No. PB82-196866), U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1981.

8. Hammond, W. F. and S. M. Weiss, Air Contaminant Emissions from Metalurgical Operations in Los Angeles County, Presented at the Air Pollution Control Institute, Los Angeles, CA, July 1964.

9. Particulate Emission Test Report for a Gray Iron Cupola at Cherryville Foundry Works, Cherryville, NC, Department of Natural and Economic Resources, Raleigh, NC, December 18, 1975.

10. Davis, J. N., A Statistical Analysis of the Operating Parameters Which Affect Air Pollution Emissions from Cupolas, Report for Doctorate thesis at Pennsylvania State University, November 1977.

11. John A. Danielson, ed., Air Pollution Engineering Manual, Second Edition, AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1973. Out of print.

12. Written Communication from Dean Packard, Department of Natural Resources, Madison, WI, to Douglas Seely, Alliance Technology, Bedford, MA, April 15, 1982.

13. Report of Particulate Emissions Testing at Opelika Foundry, Birmingham, AL, Air Pollution Control Commission, Montgomery, AL, November 30, 1977 - January 4, 1978.

14. Written Communication from Minnesota Pollution Control Agency, St. Paul, MN, to Mike Jasinski, Alliance Technology, Bedford, MA, July 12, 1982.

15. Test Report for Grey Iron Cupola of Flynn & Enrich Company, Baltimore, MD, Department of Health and Mental Hygiene, Annapolis, MD, November 1975.

16. Test Report for Grey Iron Cupola of Frederick Iron & Steel, Frederick, MD, Department of Health and Mental Hygiene, Annapolis, MD, November 1977.

17. Stack Test Report, Dunkirk Radiator Corporation Cupola Scrubber, State Department of Environmental Conservation, Region IX, Albany, NY, November 1975.

18. Particulate Emission Test Report for a Scrubber Stack for a Grey Iron Cupola of Dewey Brothers, Inc., Goldsboro, NC, Department of Natural Resources, Raleigh, NC, April 7, 1978.

19. Particulate Emission Source Test Report for a Scrubber Stack at Stovall's Foundry, Inc., Gastonia, NC, Department of Natural Resources, Raleigh, NC, July, August 1975.

20. Written Communication from Indiana Pollution Control Agency, Indianapolis, IN, to Mike Jasinski, Alliance Technology, Bedford, MA, July 12, 1982.

21. Test Report for Cupola Scrubber Stack at Swaine Robinson, Richmond, IN, State Board of Health, Indianapolis, IN, June 1975.

22. Report of Grey Iron Cupola Particulate Emission Tests for Sterling Castings Corp., Bluffton, IN, Clean Air Engineering Inc., February 1977.

23. Test Report for Grey Iron Cupola at Worthington Corp., Buffalo, NY, State Department of Environmental Conservation, Region IX, Albany, NY, November 4-5, 1976.

24. Test Report for Grey Iron Cupola at Dresser Clark, Orlean, NY, State Department of Environmental Conservation, Albany, NY, July 14, 18, 1977.

25. Test Report for Chevrolet Tonawanda Metal Casting Plant Cupola #3 and Cupola #4, Tonawanda, NY, State Department of Environmental Conservation, Albany, NY, August 1977.

26. Stack Analysis for Particulate Emission, Atlantic States Cast Iron Foundry/Scrub State Department of Environmental Protection, Trenton, N[illegible]ember 1980.

27. Calvert, S., N. C. Jhaveri, S. Young, Fine Particle Scrubber Performance Tests, EPA-650/2-74-093 (NTIS No. PB240325), U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1974.

28. Calvert S., H. F. Barbarika, C. F. Lake, National Dust Collector Model 850 Variable Rod Module Venturi Scrubber Evaluation, EPA-600/2-76-282 (NTIS No. PB263617), U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1976.

29. Calvert, S., H. F. Barbarika, G. M. Monahan, Gas-Atomized Spray Scrubber Evaluation, EPA-600/2-77-209a (NTIS No. PB274449), U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1977.

30. Greenburg, J. H., "Systems Analysis of Emissions--The Iron Foundry Industry," Chem Tech; 1-728-736, December 1971.

31. Test Report for Electric Arc Furnace at Paxton-Mitchell Foundry, Omaha, NE, Midwest Research Institute, Kansas City, MO, October 1974.

32. Test Report for Grey Iron Electric Arc Furnace at John Deere Tractor Works, East Moline, IL, Walden Research, Wilmington, MA, July 1974.

33. BCURA, Emission Behavior of Induction Furnaces in Iron Foundries, Birmingham, England, 1969, T1622. Translated from Luftuerunreinigung, 1969, 35-40.

34. Gronberg, S., Characterization of Inhalable Particulate Matter Emissions from an Iron Foundry, Lynchburg Foundry, Archer Creek Plant, EPA-600/X-85-328, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1984.

35. Particulate Emissions Measurements from the Rotoclone and General Casting Shakeout Operations of United States Pipe & Foundry, Inc., Anniston, AL, State Air Pollution Control Commission, Montgomery, AL, November 1973.

36. Source Evaluation Report for Wheland Foundry, Chattanooga, TN, Research Consultants, April 1978.

37. Report of Source Emissions Testing at Newbury Manufacturing, Talladega, AL, State Air Pollution Control Commission, Montgomery, AL, May 15-16, 1979.

38. H. R. Crabaugh, et al., "Dust and Fumes from Gray Iron Cupola: How Are They Controlled in Los Angeles County?" Air Repair, 4(3):125-130, November 1954.

39. J. M. Kane, "Equipment for Cupola Control," American Foundrymen's Society Transactions, 64:525-531, 1956.

40. John Zoller, et al., Assessment of Fugitive Particulate Emission Factors for Industrial Processes, EPA-450/3-78-107 (NTIS No. PB288859), U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1978.

41. BCURA, Arc Furnace Emission Control, Report No. 7, Commission 4, Environmental Control-Foundry Industry, Alvechurch, Birmingham, England, 1984.